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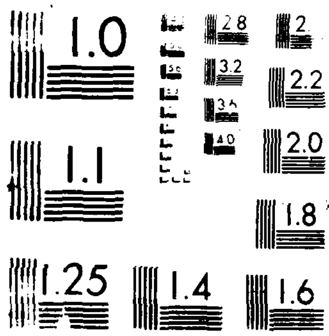
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The Pennsylvania State University

The Graduate School

Department of Meteorology

Development and Testing of an Interactive Procedure for the Improvement of Objective Analyses

A Thesis in

Meteorology

by

Thomas More Hamill

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

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Thomas More Hamill

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ABSTRACT

A software package has been developed for the Penn State/National Center for Atmospheric Research Mesoscale Model to allow interactive bogusing. This package was developed to allow the production of more realistic objective analyses. Previously, the process of inserting synthetic data in order to improve the objective analysis was done manually, which was inefficient and time-consuming. The new procedure described in this thesis uses newly developed bogusing software to make the process more efficient. The software has three parts: a data creation (bogusing) component, an objective analysis component, and graphics routines for displaying objective analysis output. To use this software, the user transfers an objective analysis from NCAR, where it was generated on the CRAY computer, to the user's local site. Next, these data are loaded into a supermicrocomputer. Using the graphics software, the user checks the analyses to see if bogus data are needed. If so, the bogusing software is used to efficiently create the synthetic data, and the objective analysis software is run to analyze the influence of these data. The user then reexamines the analyses with the interactive graphics software and can repeat the cycle as needed until the desired initial conditions are created. These newly created bogus data are then sent back to the CRAY for use as numerical model initial conditions.

A test case was run to demonstrate the capabilities and limitations of the software. The test case demonstrated that time savings may be quite great compared to use of the existing noninteractive procedure. It is suggested that interactive human-machine analysis software may be useful in an operational setting like that at the National Meteorological Center.

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Two people, though, were absolutely indispensible to completion of this thesis. They are Dr Thomas Warner, my thesis advisor, and Patricia Waukau, a computer manager at NCAR. I thank Dr Warner for his continual help in setting a direction for my research and removing the obstacles to completing it. I thank Pat Waukau for her help with the software problems. She gave more help and had more patience than I had any right to expect.

Chapter 1

INTRODUCTION

"Gigo," or "garbage in, garbage out," is a popular phrase and one useful as an introduction to the problem this thesis will address. It summarizes what might more eloquently be expressed as, "the output of your computer program can be only as good as your input." In numerical weather prediction (NWP) applications, it means that poorly defined model initial conditions will generally result in a poor forecast. Nonlinear interactions described by the model dynamics spread initial errors throughout the spectrum of allowable motions, degrading forecast skill with time. Generally these poorly defined initial conditions result from a lack of data or their improper processing.

Analyses of initial conditions can be generated by a computer or a human. Each way has advantages. Humans are more accurate in the sense that trained synopticians can incorporate their training, nonstandard data sources, and conceptual models of the structure of weather systems into a highly detailed and accurate representation of the analyzed field (i.e., a subjective analysis [SA]). In contrast, a computer must be programmed with a fixed set of algorithms, and the resulting analysis can only be as good as the algorithms. The analysis of meteorological fields by a computer which utilizes a set of preprogrammed "rules" is defined as objective analysis (OA). OAs have two great advantages over SAs, the first being speed. Today's computers can analyze in seconds or minutes what would take weeks to do by SA. Such speed is crucial, especially in operational numerical weather prediction; model output must be speedily disseminated to the meteorological community in order to produce timely forecasts. The second advantage is numerical simplicity and consistency; OAs output the data on a grid suitable for model initialization, a laborious process for a human. Further, their algorithms can be designed to remove spurious imbalances and short-wavelength features inevitable in SAs. For these reasons, OA is uniformly used rather than SA to define initial conditions. The compromise in accuracy should not be overstated, either; with today's supercomputers, complex algorithms have been designed which often do a very good job of defining initial conditions for synoptic-scale flow regimes.

Nonetheless, OA schemes can only be as accurate as their data will allow. Currently, the primary data source for OAs is rawinsonde balloon data. Over the conterminous United States, rawinsonde launching sites are separated by 380 km, on the average. Hence, the OA may accurately resolve flow patterns with wavelengths of thousands of kilometers, since such waves are defined by dozens of rawinsonde observations. Smaller scales, however, are more poorly defined; there are not enough rawinsonde observations to credibly resolve them. Resolving these features can often be crucial in producing a reliable forecast. Zhang and Fritsch (1986), in a modeling study of the Johnstown flood of July 1977, obtained the best modeling results after incorporating thirty bogus, or subjectively determined, soundings into the data set used as input to the OA. In the future, it is hoped that automated reporting stations, Doppler profilers and radars, and remote sensing devices will provide enough data of good enough quality to obviate the need for bogus data. In that regard, some gratifying results have been obtained by assimilating new data sources into the OA. Cram and Kaplan (1985) used a variational objective analysis method to assimilate satellite temperature and moisture-gradient information. Their results showed notable improvement in the forecasts of patterns of convective instability. Nonetheless, for the foreseeable future, rawinsondes will remain the primary data source for OAs, thus effectively limiting their spatial resolution to the synoptic scale.

Having to rely on these rawinsonde data presents other problems. One such problem is that rawinsondes record a quasi-vertical profile of temperature and humidity, data which will implicitly reflect all scales of motion. OA's, however, assume that these profiles are representative of the state of the atmosphere in a large volume surrounding the place of balloon ascent. In other words, these algorithms assume that all the rawinsonde data represent only synoptic-scale information; hence, these data are used to estimate the state of the atmosphere for a large area surrounding the launch site. One can see that a rawinsonde balloon whose trajectory takes it through an active thunderstorm will relay data which does not primarily represent synoptic-scale information. Similarly, a rawinsonde which rises through the middle of a jet streak or on one side of an intense front will contain information of mesoscale features, not just synoptic-scale. Including such data into the OA would degrade the quality of the initial conditions, so some human intervention is needed.

Another problem is the lack of observations over the ocean. Observations there are limited to infrequent and often sparse ship and plane reports and information from satellites. Recent advances in remote sensing have improved coverage over oceans, but their vertical resolution is not comparable to rawinsondes, and vertical resolution may be crucial in areas of baroclinicity and cyclone development.

Some of the most notably poor model performances have occurred because of inadequate analyses over the ocean. Of particular note was the Presidents' Day Storm of 1979, a storm which travelled up the mid-Atlantic coast, leaving 40 to 60 cm of snow in its wake, and the QE II storm of 10-11 September 1978, so named because of the extensive damage by wind and waves to the Queen Elizabeth II ocean liner. The Presidents' Day Storm has been examined by Bosart (1981), Uccellini et al. (1984), and Uccellini et al. (1985). The QE II storm has been reported on by Gyakum (1983a,b), Anthes et al. (1983), and by Uccellini (1986). Hales (1979) described an eastern Pacific storm in which National

Meteorological Center's (NMC's) Limited-Area Fine Mesh Model (LFM-II) produced an inaccurate forecast due to poor initial conditions, but which satellite imagery clearly resolved. A more recent case was presenteded by Reed and Albright (1986). They describe a rapidly developing storm in the eastern Pacific on 13-14 November 1981 which the LFM-II failed to forecast, resulting in a 24-h forecast error of 55 mb at the center of the storm. Presumably, all these storms would have been better forecasted had there been more observations over the sea.

Too few observations may result in a poor OA, but on occasion, the distribution of observations can also influence its quality. Consider a rawinsonde fortuitously launched through the center of a deep cyclone. If the data from this rawinsonde are used exclusively to define the central pressure in the low, this central pressure may be defined very accurately. If other rawinsondes are launched nearby, but at locations with higher pressure, and if the algorithms specify that the area of influence for these observations overlaps the center of the low, then the higher pressure readings may "wash out" the correct, lower one. Similarly, temperature and moisture gradients within frontal zones and wind gradients near jet streaks may be washed out by the OA.

A case is being built for some alternative process to the pure OA or SA. We have seen that SA is too slow and the OA is frequently not accurate enough for forecasting needs, given data voids and meteorological processes at small length scales. Sometimes, an alternative becomes absolutely necessary. For example, investigators performing NWP research into processes at the mesoscale length scales often find pure OAs unsuitable; the correct resolution of smaller-scale features in the initial conditions often becomes critical in order to accurately forecast these smaller scales (Zhang and Fritsch, 1986).

The approach most often used in research meteorology to extend the capabilities of OA involves creating bogus data, to make the initial conditions more accurate. Perhaps the analyst has a mental picture of how the feature should look, given the data, the OA, previous experience, and an understanding of the dynamics. He has looked at many similar cases and has a composite picture in mind as well as some idea of the differences between the composite and the feature in question. He can mentally add detail in data-sparse regions, use data sources not included in the OA, and spot poor analyses resulting from overly simplistic algorithms. This analyst then creates bogus data which will hopefully result in the OA producing initial conditions that replicate the feature as imagined.

As it exists currently, however, this process is mechanically very cumbersome. The OA and the numerical model currently used for research at this institution, Penn State, is MM4, the PSU/NCAR Mesoscale Model, described by Anthes and Warner (1978). This modeling system is run on the National Center for Atmospheric Research's (NCAR) Cray X-MP computer, which is non-interactive. Previously, the analyst subjectively determined the flaws with the OA performed at NCAR, created bogus rawinsonde data from available information, and submitted these data via telephone lines to the Cray. OA output was transferred to microfilm and mailed for examination. If the output looked acceptable, the model was run; if not, the process was repeated. This process of creating, inserting, and analyzing the contribution of bogus data took months. This "bogusing" process was frequently the longest step in running a research model, and clearly it could not have been used to remedy poor OAs in real-time NWP models.

However, an interactive objective analysis, graphics, and bogusing software package has been developed at The Pennsylvania State University which can greatly reduce the time spent producing suitable bogus data. This package runs on a supermicrocomputer and has a simplified OA program which mimics the one on the Cray in most aspects. Its graphics package can quickly plot fields of interest from the OA output. Finally, its bogusing software allows the user to modify soundings plotted with the graphics software, creating the false data for use in a subsequent OA. These programs work interactively and greatly reduce the overhead time necessary to produce suitable initial conditions. With further refinements in the area of interactive analysis, the time savings may prove great enough that such a system could work in an operational setting.

In the following chapter, OA algorithms used in the research model will be described. The interactive bogusing software package will be described in Chapter 3, as well as how this software fits into the hierarchy of the research model. A sample test case is described in Chapter 4 which demonstrates the potential and the limitations of this software and of bogusing in general. Concluding remarks will follow in Chapter 5.

Chapter 2

A SURVEY OF OBJECTIVE ANALYSIS METHODS

As mentioned in Chapter 1, efficiency considerations make the use of OA algorithms imperative in NWP, in contrast to the use of subjective techniques. There are three commonly used OA algorithms: successive corrections, optimum interpolation, and variational. The successive-corrections technique is the simplest of the three. An advanced successive-corrections scheme employing anisotropic weighting functions is used in the PSU/NCAR model and for this research. Alternatives to the method of successive corrections will be mentioned first, then general aspects of the successive-corrections method will be described in Section 2.2, and the specific scheme used for this reseach will be described in Section 2.3.

2.1 Alternatives to the Successive-Corrections Procedure

Even though the successive-corrections scheme is used in this research, other methods do exist. One of these is optimum interpolation, discussed in more depth in Schlatter (1975). This is currently the most widely used scheme at operational meteorological centers around the world. However, it is computationally very expensive. It is a statistical scheme for the simultaneous analysis of the wind and geopotential-height field. Past climatological behavior of the height and wind fields in the vicinity of a grid point is taken into account. A matrix of weights is set up and applied to observation vectors. These weights depend upon the covariances of observed minus forecast differences. The large number of operations required to invert the covariance matrix makes this scheme very time-consuming, but because mutual correlations between the mass and motion fields are taken into account, it is also highly accurate.

Another highly accurate scheme is variational analysis (Sasaki 1958). This technique is based on the calculus of variations and minimizes the difference between objectively analyzed values and initial values, subject to dynamical constraints such as the balance equation or the thermal wind law. This procedure is also very accurate, since meteorologically valid dynamical constraints are used in the analysis. Multiple constraints can be used, and the strength of the constraints can be controlled. The accuracy of the observations is included in the weighting factor, though it is difficult to determine the weights. As with variational analysis, this method is computationally time-consuming and thus expensive to use.

2.2 The Method of Successive Corrections

The most computationally inexpensive method of OA is the method of successive corrections. With this method, corrections are applied to a first-guess field, based upon the new data. The corrections are determined from a comparison of the data with the interpolated value of the guess at the observation point. A series of scans of the field is made, each scan consisting of application of corrections on a smaller lateral scale than the previous scan (Cressman 1959).

Before the actual analysis is performed, data are checked for reliability. Temperature soundings are subjected to a hydrostatic check, and superadiabatic lapse rates are adjusted. Wind soundings are checked for vertical consistency, and erroneous parts of the report are deleted.

Each horizontal field is analyzed separately. The first guess is typically the previous twelve hour forecast, though RAWINS/NCAR, the MM4 model's OA package, uses NMC global analyses for the first guess. Next, at each observation point, a bilinear interpolation is made from the four grid points surrounding the observation point to get a gridded value for the first guess there. A sweep is then made through all the grid points in the model domain. At each grid point, the distance to nearby observation points is calculated. A weighting factor for the amount of correction to the value at that grid point is then calculated for each nearby observation point. In the simplest scheme, the weighting factor W is given by

$$W = \frac{N^2 - d^2}{N^2 + d^2} \quad \text{if} \quad d < N \qquad 2.1$$

$$W = 0.0 \quad \text{if} \quad d \geq N$$

In the expression for W, d is the distance between the grid point and the observation point and N is the radius of influence, the distance at which W becomes zero. For the first scan, N is usually set to 555 km, 1.6 times the average distance between U.S. rawinsonde launching sites. The computation of the grid-point value of a variable α then proceeds according to the relation

2.2 $$a'_{ij} = a_{0ij} + \Delta a_{ij}$$

where

$$\Delta a_{ij} = \frac{\sum_{k=1}^{K} [W^2 \Delta a_k]}{\sum_{k=1}^{K} W}$$

and

a'_{ij} = adjusted value of a at grid point (i,j),

a_{0ij} = first guess for variable a at (i,j),

Δa_{ij} = adjustment at the grid point (i,j) based on all data with d < N,

Δa_k = difference between analysis and observation at observation point k, and

K = number of observations with nonzero weighting values for grid point (i,j)

(Benjamin and Seaman, 1985). After the sweep is completed, N is typically decreased to 70% of its previous value, and another sweep progresses. A third and usually final sweep ensues after another .7 decrease in N. Typically, after the three passes, the field is smoothed.

2.3 The RAWINS/NCAR Objective Analysis Package

RAWINS/NCAR is the objective analysis package for the PSU/NCAR mesoscale model. An important property that represents a departure from Cressman's originial procedure is the capability of using anisotropic weighting functions. The weighting function described in the previous section was an isotropic, or circular one; two rawinsonde reports an equal distance from a given grid point were assigned the same weight. However, a better analysis can often be produced by changing the shape of the weighting function. At a given point, wind, moisture, and geopotential height values are sometimes better correlated with other values along the streamline through the point than with values at a similar distance crosswind. Hence, in a successive correction scheme, it would make sense to give greater weight to observations along the streamline than to crosswind observations. RAWINS/NCAR allows the user to decide whether or not to use these anisotropic weighting functions. Should the user choose to use anisotropic ones, if the wind at a point is greater than a certain magnitude, then an elliptical or a banana-shaped weighting function will be used to analyze the wind and moisture fields (RAWINS/NCAR does not analyze geopotential height, but calculates it later from the objectively analyzed temperature fields). A banana-shaped function is used when the flow is highly curved, and an elliptically shaped one when the flow is relatively straight. In both cases, the stronger the wind, the more elongated the weighting function.

The mathematical descriptions of the anisotropic weighting functions, as well as criteria for their use, are given in Benjamin and Seaman (1985). A description of the RAWINS/NCAR program itself is given in Seaman (1986).

Chapter 3

A DESCRIPTION OF THE SOFTWARE

3.1 A Comparison Between the Conventional and Experimental Methods of Bogusing

In order to improve the quality of MM4 model initial conditions and the speed in determining them, a bogusing software package has been designed which enables the user to quickly evaluate the impact of bogus data by using a DEC Microvax II graphics workstation. This allows the user to quickly examine his OA, to design bogus data, and to examine its effect upon the quality of initial conditions,all in an interactive mode.

Figures 3.1 and 3.2 illustrate the bogusing processes that employ the conventional and experimental software, respectively. With both methods, the process was assumed to start by running RAWINS/NCAR. In the conventional method, bogusing is performed inefficiently by executing the RAWINS/NCAR in batch mode on the Cray. Figure 3.2 charts the new, experimental method, performed at the user's site (in this case, at Penn State). Its output is then processed through a program, DATAFLOW, at NCAR. This program calculates additional diagnostic variables, converts the fields to sigma levels, and outputs the data.

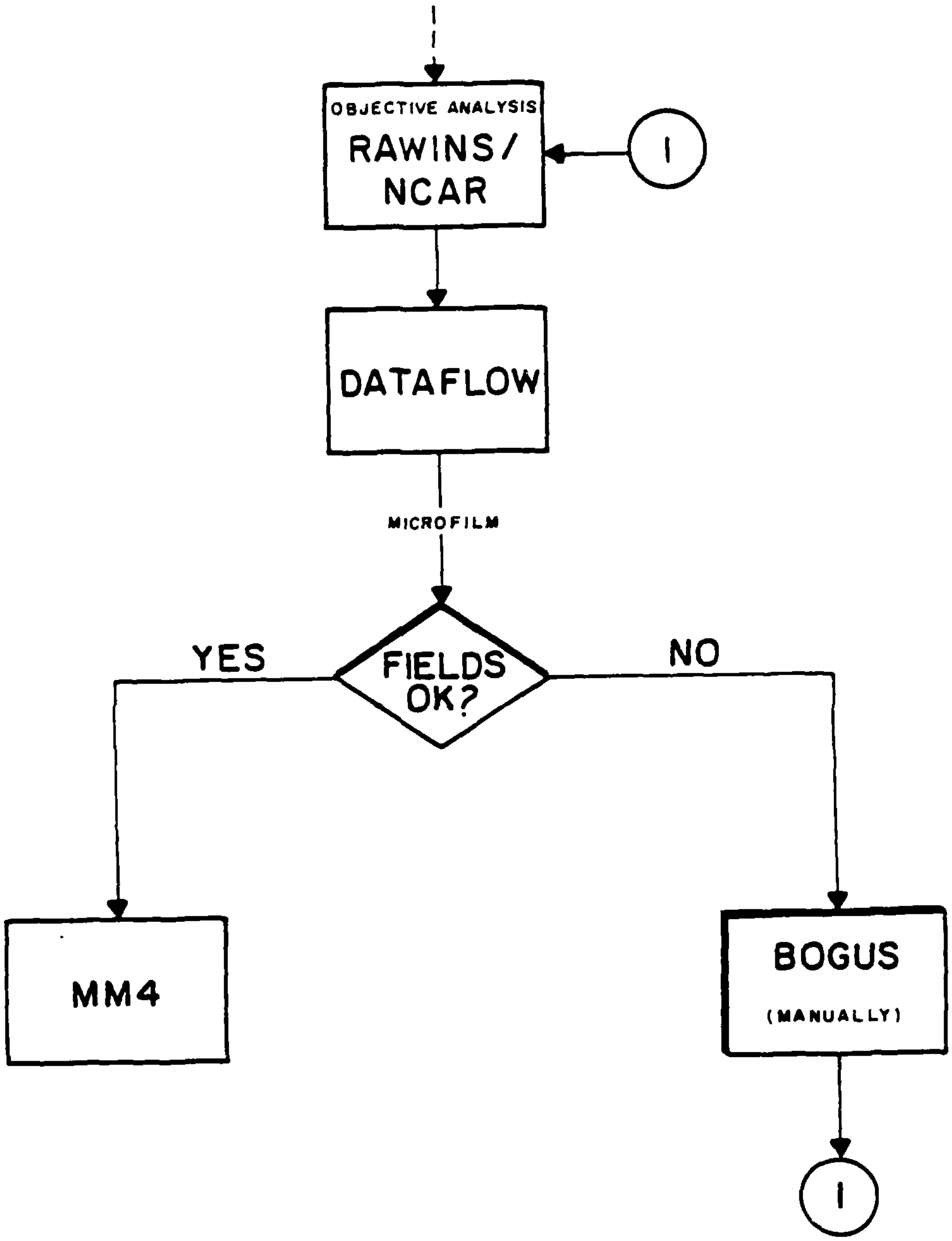


Figure 3.1 Flowchart for the conventional method of bogusing. Highlighted boxes denote steps carried out at Penn State.

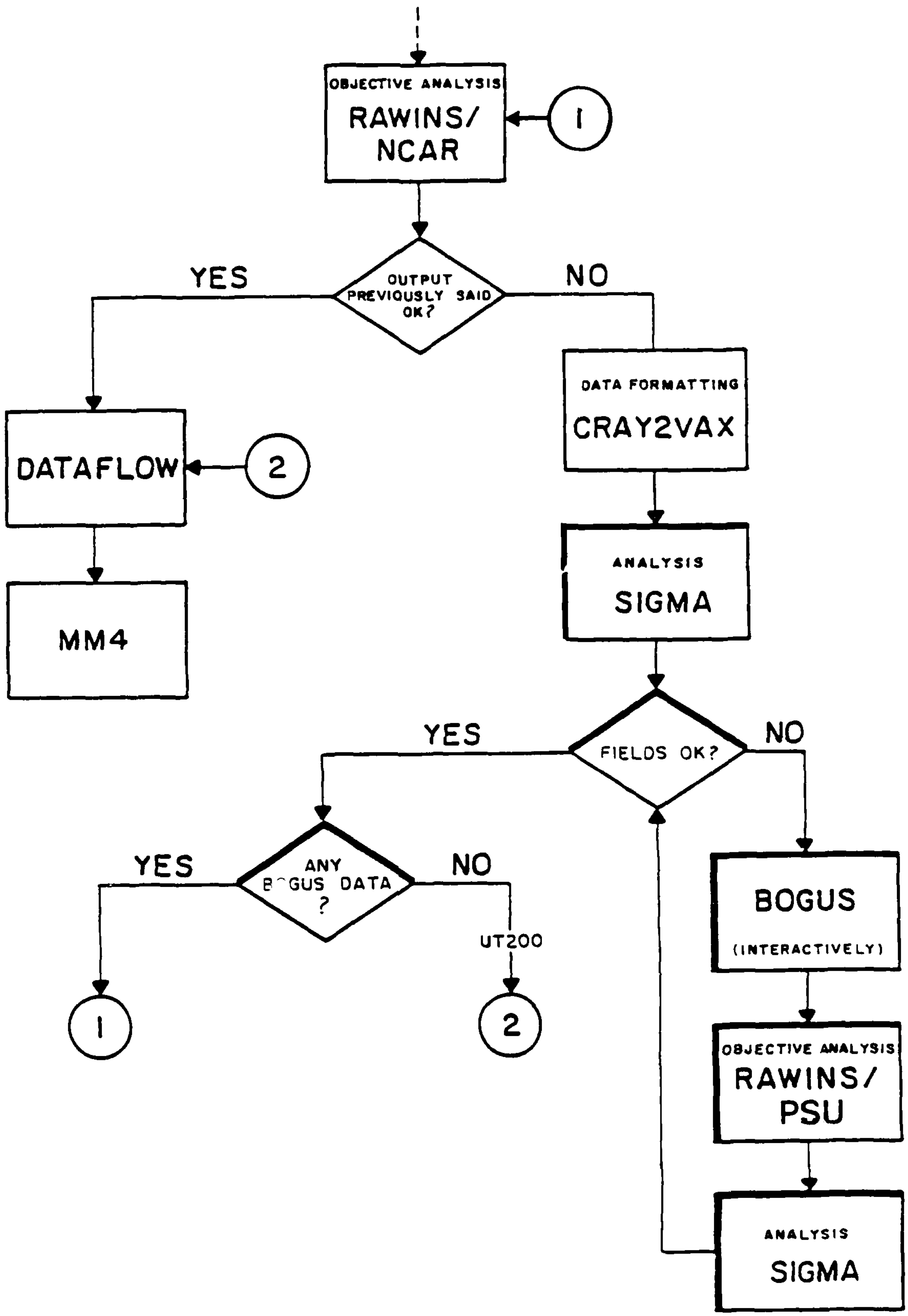


Figure 3.2 Flowchart for the experimental method of bogusing. Highlighted boxes denote steps carried out at Penn State.

3.1.1 The Conventional Method

After DATAFLOW is executed, we transfer the data to microfilm and mail it back to Penn State. The user then carefully examines the microfilm data. Discrepancies between the conceptualization of the way the fields should appear and the way they appear in the OA are reconciled by manually designing bogus data. These data are sent via telephone line back to the Cray, and RAWINS/NCAR is run again. Again, DATAFLOW is run and microfilm is created and mailed back to the user. This cycle is repeated until the user is satisfied with the initial conditions. Only then is the MM4 model run.

There are two problems with this method: it is time consuming and costly. The iteration of the process is time consuming because the design of bogus data by hand involves many careful calculations; haphazard changes in the temperature and moisture profiles often induce unwanted changes in the geopotential-height field. The user has to anticipate these effects by calculating the changes that will be induced in the geopotential-height field, a tedious process using a hand calculator.

Also, because bogus observations are merely included with the standard rawinsonde observations, their influence is often "washed out." To remedy this, the user has two alternatives. First, the bogus data values can be chosen in anticipation of this dilution effect by the other data. For example, if the user believes the surface pressure is 5 mb too high at a given location, a bogus observation with a pressure 10 mb lower could be used. A second method is to use a large number of bogus observations in a small area. The large number of observations diminishes the influence of the surrounding, regular rawinsonde data. Both of these methods often require multiple iterations of the process to get acceptable initial conditions, thus requiring running RAWINS/NCAR and DATAFLOW many times.

3.1.2 The Experimental Method

A new way of approaching the bogusing process has been developed (Figure 3.2). As with the old method, a preliminary run of RAWINS/NCAR is necessary. These data are then transferred to tape, mailed back to the user, and loaded into the microcomputer. Residing in the computer is a simplified OA package (RAWINS/PSU), a data creation (bogusing) package, and a graphics package. The OA package uses RAWINS/NCAR output for its first guess and analyzes only the contribution of bogus data. The bogusing package allows the user to conveniently produce bogus data and check its consistency by plotting the bogus data in Skew-T form. It also calculates geopotential height from the new temperature field and formats all the bogus data in a format acceptable for input into the OA programs. The graphics package, SIGMA (Software for Interactive Graphics and Model Analysis), developed at NCAR, is an interactive analysis package which allows the user to plot MM4, RAWINS/NCAR and

RAWINS/PSU data in various forms, including horizontal maps, vertical cross-sections, Skew-T's, hodographs, 3-D perspectives, etc. The three software elements, the OA, bogusing, and graphics segments, all work interactively and allow the user to produce quality bogus data in a minimum of time.

Another important change involved a modification to RAWINS/NCAR. A switch was inserted which allowed the first guess fields for the OA to come from NMC data (the conventional method) or from the previous RAWINS/NCAR analysis (the experimental method). With the latter option, the only data to be objectively analyzed are the bogus data. This option was added to ensure compatibility between RAWINS/NCAR and RAWINS/PSU analyses.

3.2 Penn State's Bogusing Software

3.2.1 The Graphics Software (SIGMA)

The heart of the interactive bogusing software is a state-of-the-art graphics package which provides the user flexibility in displaying digitized fields. SIGMA is built around NCAR-Graphics software and has been tailored to work with RAWINS and MM4 data. With SIGMA, the user can create horizontal maps, vertical cross-sections, hodographs, Skew-T's, trajectories, streamline analyses, and vector plots. The program can also perform stereo projections (with a color monitor). Display options are entered in the form of command lines. For example, a horizontal vector plot of temperature at 500 mb would be produced by the command line

2D,LOC=8,FLD=T <RETURN>

The '2D' indicates that the plot is to be a horizontal, two-dimensional contour plot, the 'LOC=8' specifies which vertical level in the data set is 500 mb is, and 'FLD=T' declares the field to plot is temperature. Figure 3.3 shows the resultant plot, with map base overlaid.

3.2.2 The Objective Analysis Software: RAWINS/PSU

In all important aspects, RAWINS/PSU is identical to RAWINS/NCAR. Both are successive correction schemes employing anisotropic weighting functions. However, RAWINS/PSU is run within SIGMA, it can analyze all or a few of the levels and fields, and it analyzes only the effect of adding bogus data.

RAWINS/PSU was integrated into SIGMA rather than being maintained as a separate program for several reasons, notably for programming simplicity and ease of use. By integrating RAWINS/PSU into SIGMA, the program can utilize the sophisticated disk-mapping routines for data input and output. More importantly, however, it provides a consistent user-interface. Objective analysis options are entered on a SIGMA command line. This command line contains information about what fields are to be analyzed (e.g.., temperature at a particular level, or surface pressure), whether or not to recalculate geopotential heights, and what bogus data to

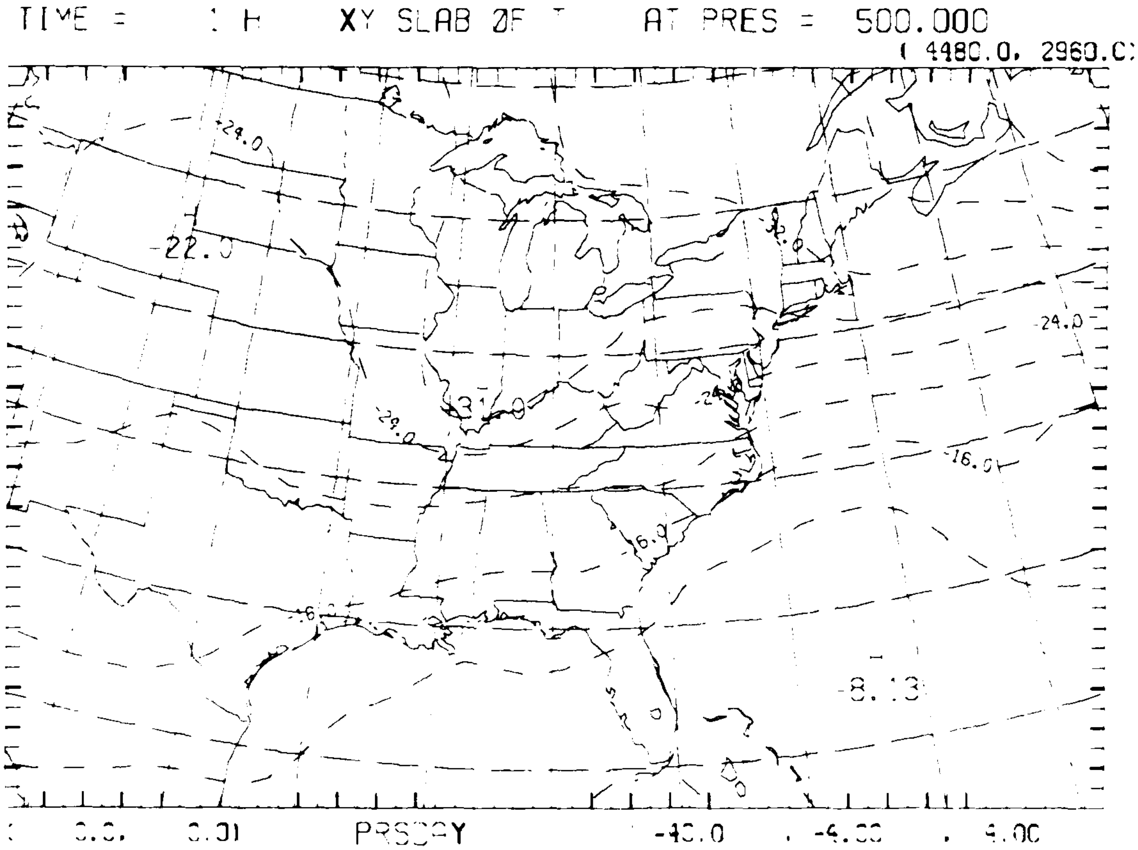


Figure 3.3 Demonstration plot using SIGMA software of RAWINS/NCAR-analyzed 500 mb temperature for 0000 GMT 19 December 1979.

use. A typical RAWINS/PSU command line might be

RAWINS,BOG=[HAMILL]PSUBOG.DAT,ANL=950T/500A

This tells the computer to enter the RAWINS subroutine, to get the bogus data from the file "[HAMILL]PSUBOG.DAT", and to objectively analyze the 950 mb temperature field and all the fields at 500 mb (U, V, T, and RH).

As mentioned above, no conventional rawinsonde data are analyzed, only bogus data. Conventional data are assumed to have been included in the analysis by RAWINS/NCAR. This speeds up the analysis process and allows the program to be run on the comparatively slow Microvax. As noted, the first guess for the OA is RAWINS/NCAR output. To make the RAWINS/NCAR and RAWINS/PSU analysis routines identical, RAWINS/NCAR was modified to allow the first guess to come from a previous OA, and also to allow the option of processing only bogus data. Thus, an OA locally produced on the Microvax should be identical to one run with the same data on the Cray.

3.2.3 The Bogusing Software

The bogusing software was designed to produce and format bogus data quickly and easily so they are acceptable as input to RAWINS/NCAR and RAWINS/PSU. There are three main components to this bogusing software: The first is a component that creates or calls from memory a "template" of bogus data for a given location. The template contains one line for each level that RAWINS will analyze, as well as the location of the data points and other information. The second component allows efficient data creation and modification. The third is a postprocessor which takes all the bogus data and concatenates it into one file in a format acceptable to RAWINS/NCAR and RAWINS/PSU.

The template for the bogus data is a table filled with 9's as placeholders for the bogus data. A sample template is shown in Figure 3.4. In this example, the meteorological sounding data have not yet been specified. By entering the grid points where one wishes to add a bogus sounding, the computer searches its memory to see if a template was already created for that location. If it finds one, it recalls it from memory. If not, it creates a new template. The template contains two lines with information on the location, the number of levels, the type of levels (mandatory or significant), and the elevation above sea level. The rest of the lines are filled with placeholding 9's over which the bogus data are written.

The data creation software then allows the user to specify bogus data values and then inserts this information into the template in the correct format. The user can set the terrain height, the surface pressure, and for each vertical level the user can specify the geopotential height, temperature, dewpoint depression, wind direction, and wind speed.

```
                                                        (2a)       (2b)         (2c)
(1) 100100 BOG
(2) DATE,ID,IMAN,NLV,LAT,LON,ELEV,                       1       28.7 -100.6    0.0
              1000.0   99999.9     999.9    999.9      999.9        999.9
               850.0   99999.9     999.9    999.9      999.9        999.9
               700.0   99999.9     999.9    999.9      999.9        999.9
               500.0   99999.9     999.9    999.9      999.9        999.9
               400.0   99999.9     999.9    999.9      999.9        999.9
               300.0   99999.9     999.9    999.9      999.9        999.9
               250.0   99999.9     999.9    999.9      999.9        999.9
               200.0   99999.9     999.9    999.9      999.9        999.9
               150.0   99999.9     999.9    999.9      999.9        999.9
               100.0   99999.9     999.9    999.9      999.9        999.9
    DATE,ID,IMAN,NLV,LAT,LON,ELEV,                      -1       28.7 -100.6    0.0
                 SFP   99999.9     999.9    999.9      999.9        999.9
               950.0   99999.9     999.9    999.9      999.9        999.9
               900.0   99999.9     999.9    999.9      999.9        999.9
               800.0   99999.9     999.9    999.9      999.9        999.9
               750.0   99999.9     999.9    999.9      999.9        999.9
    END
                 (3)     (4)        (5)      (6)        (7)          (8)
```

Figure 3.4 A sample template. Field (1) gives the grid point location of the bogus station, here (10.0,10.0). Field (2) is a line which specifies the date and the number of the bogus station (both have not yet been entered), the type of data (2a), "1" for mandatory, "-1" for significant, the number of levels (not yet entered), the latitude and longitude (2b), and the terrain height (2c). Tabular data then follow, with mandatory-level data followed by significant-level data. Data are formatted into rows for each pressure level. Each column denotes a data type. (3) gives the pressure level for the row, (4) the geopotential height at this level, (5) the temperature (6) the dewpoint depression, (7) the wind direction, and (8) the wind speed.

When the user is satisfied with the set of files of bogus data that have been created, the postprocessor searches each bogus data file and removes any lines where no data were inserted. It then concatenates all the bogus data files into one master file in a format acceptable to RAWINS. RAWINS/PSU or RAWINS/NCAR can then be run, using these data as input.

A final, important component of the bogusing software is actually part of SIGMA. The Skew-T program in SIGMA now has the capablility to plot out a sounding modified with bogus data and to automatically calculate and plot out geopotential heights at each level. In this way, the user can examine the influence of his bogusing on the pre-existing sounding, checking for errors and vertical consistency without doing an OA.

Chapter 4

AN EXAMPLE OF THE USE OF THE BOGUSING SOFTWARE

To demonstrate the potential of the bogusing software, a case study was run on the Presidents' Day Storm of 1979. This storm was notable both for its large snowfall amounts (up to 60 cm in Maryland and Virginia) and because NMC's operational models, the LFM-II and the Seven-Layer Primitive Equation model, both failed to forecast the sudden cyclogenesis and the heavy precipitation amounts. Bosart (1981) concluded that this was due to initial analysis deficiencies coupled with inadequate boundary-layer and convective-precipitation parameterization. Indeed, initial conditions for the model runs preceding the storm were very poor, due to the lack of data over the ocean and inadequate resolution of the cold-air damming and coastal front. This, plus the fact that the storm is already well-known by the research community, makes it an excellent storm with which to illustrate the capabilities of the bogusing software.

Since an object of this thesis is to suggest the future feasibility of interactive analysis software in an operational setting like NMC, analysis options were chosen to closely mimic those in NMC's current state-of-the-art model, the Nested Grid Model (NGM). A horizontal grid spacing of 80 km was chosen, since this closely approximates the resolution in the fine mesh of the NGM. Analyses of temperature, relative humidity, and wind components were performed at 950, 900, 800, and 750 mb as well as at all the mandatory levels up to 100 mb. The initial analyses were produced by RAWINS/NCAR using 0000 Greenwich Mean Time (GMT) 19 February 1979 data.

After discussing the SAs for the case and their differences from the RAWINS/NCAR-produced analyses (the first guess fields for the bogusing), a new, interactively-bogused set of improved initial conditions will be shown and discussed. The new bogusing techniques, as well as the limitations and capabilities of the software, will also be discussed. A synoptic discussion of this storm will not be given; for such, see Bosart (1981) or Uccellini et al. (1984).

4.1 Subjective Analyses of 0000 GMT 19 February 1979 Data

SAs were performed for those variables and levels where bogus data are to be used in order to improve the first guess fields from the RAWINS/NCAR OA. Figures 4.1 through 4.4 show SAs for levels at or below 850 mb. As will be explained later, there was no information above 850 mb to use in the bogusing process, and thus the SAs will not be exhibited for the middle and upper troposphere.

A variety of data sources were used to produce these analyses. Over the conterminous U.S., the primary data source came from the rawinsonde network and FAA 604 data. Over the ocean, satellite pictures, sea surface temperatures, and ship and buoy data guided the subjective modification of the RAWINS/NCAR OA.

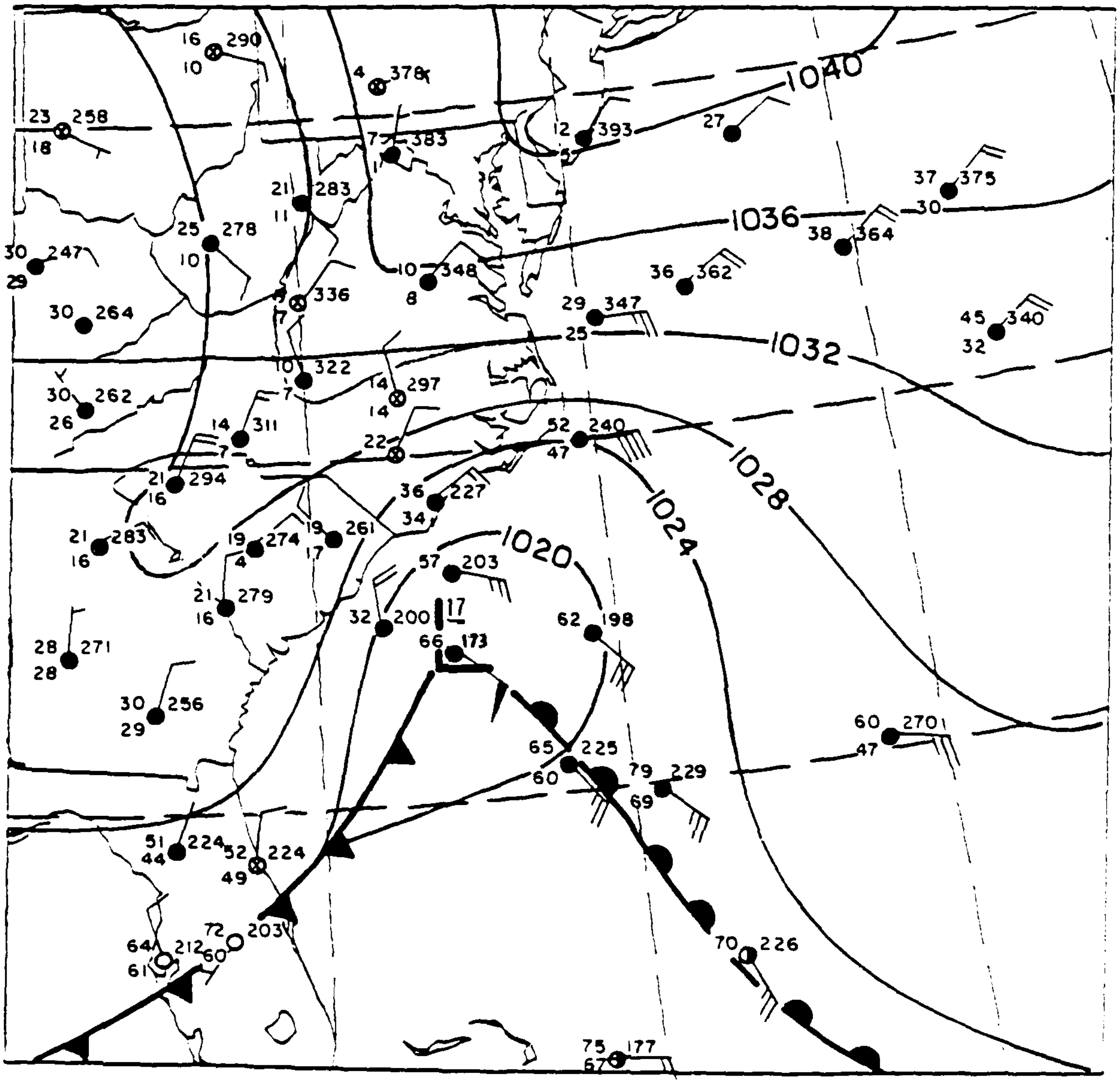
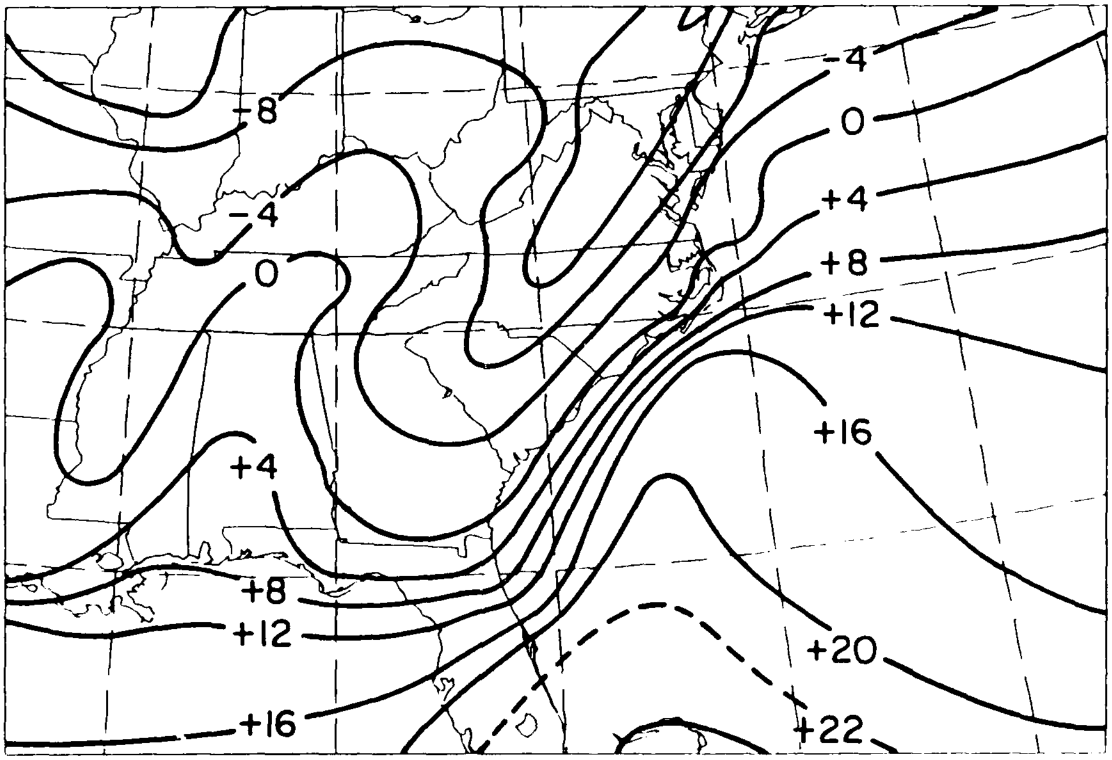
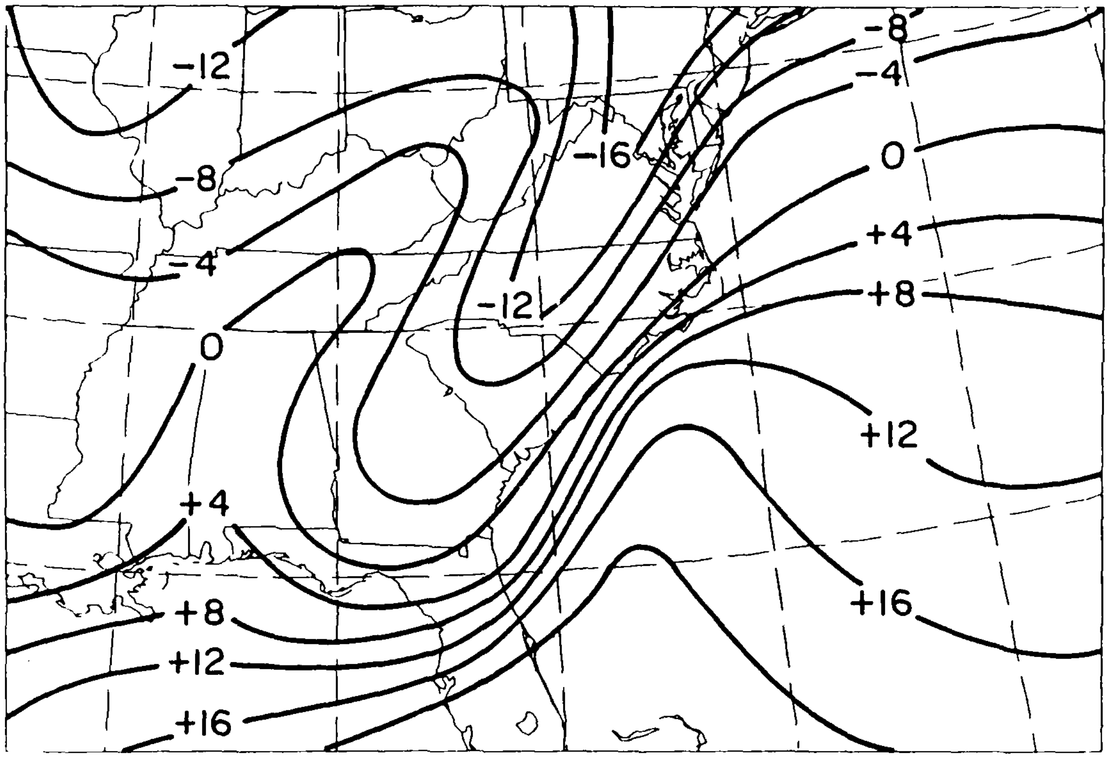


Figure 4.1 Subjective sea-level pressure analysis for 0000 GMT 19 February 1979. Precipitation symbols and pressure tendency have been omitted from the station plotting model. The contour interval is 4 mb.

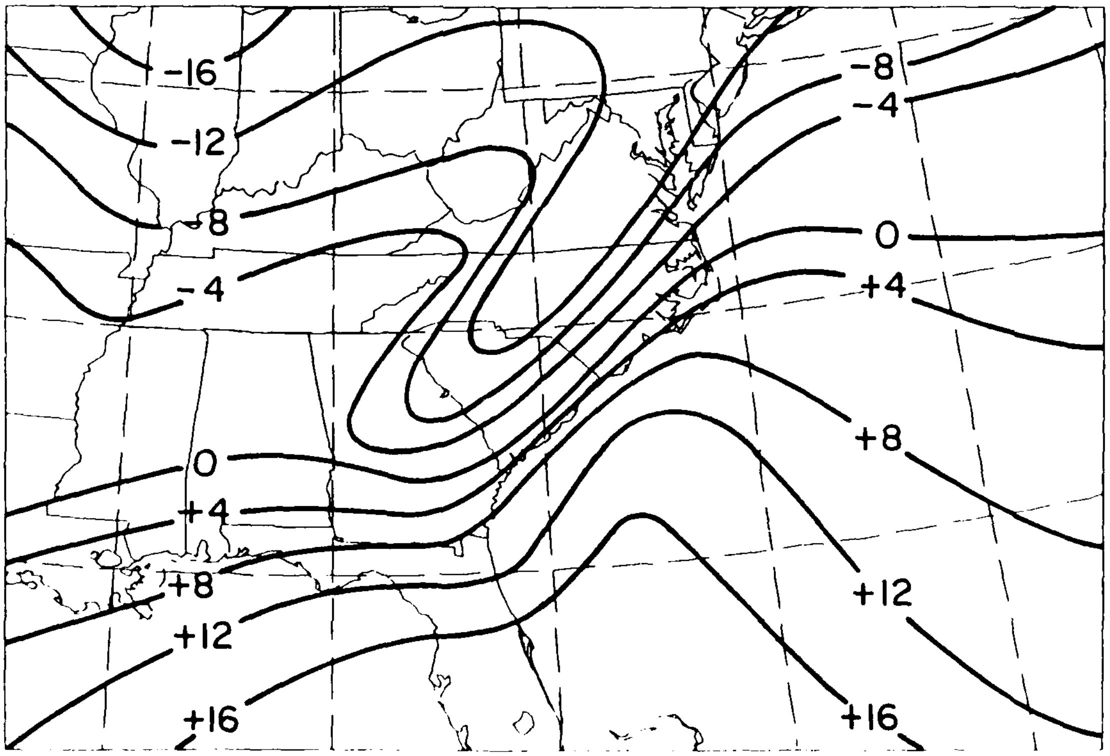


(a) surface

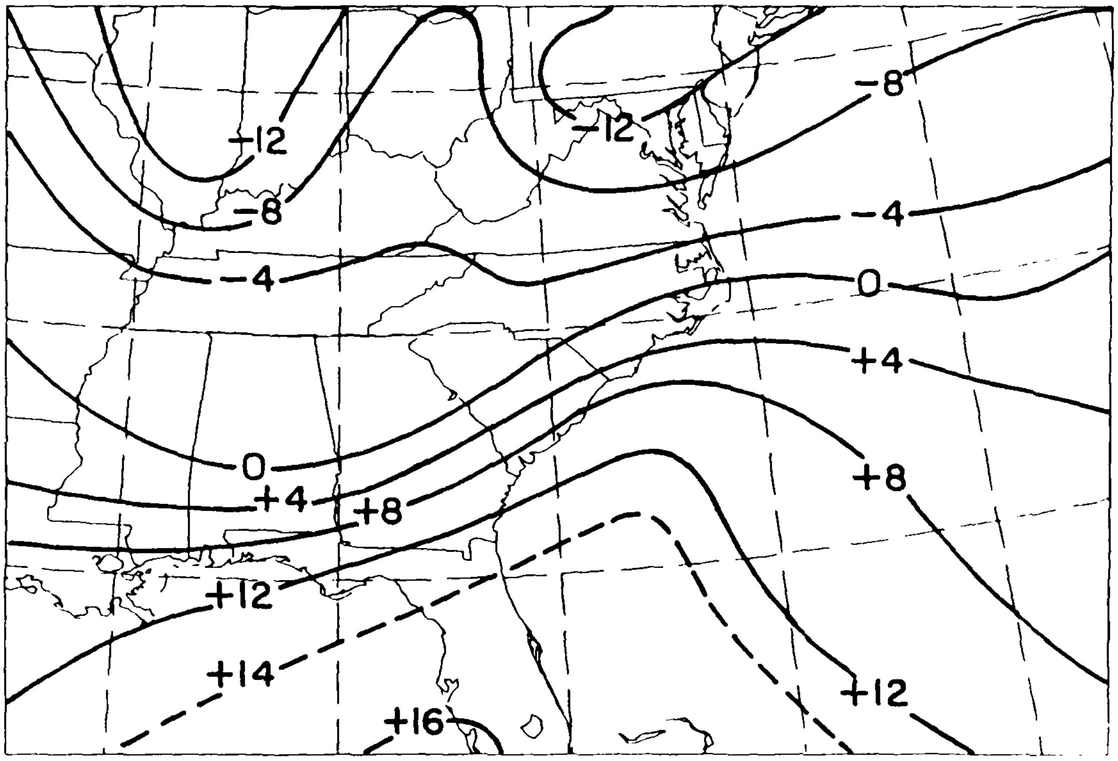
Figure 4.2 Subjective analyses of temperature for (a) surface, (b) 1000 mb, (c) 950 mb, (d) 900 mb, and (e) 850 mb. The contour interval is 4C.



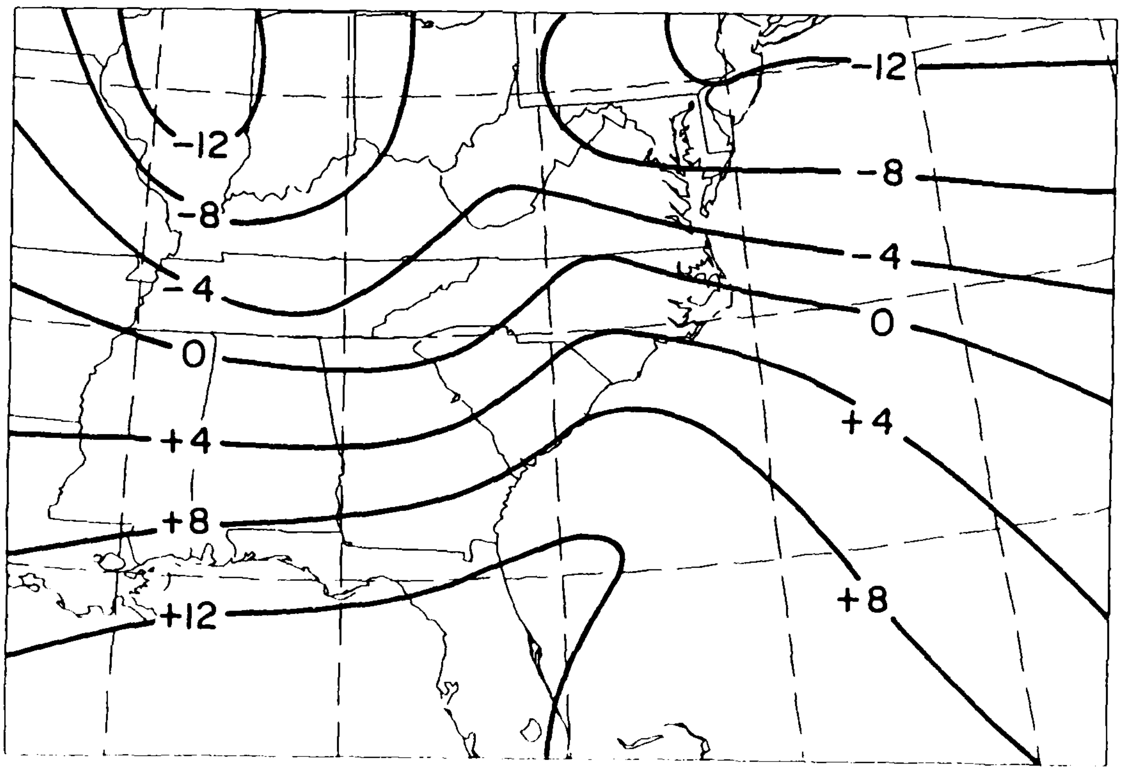
(b) 1000 mb



(c) 950 mb



(d) 900 mb



(e) 850 mb

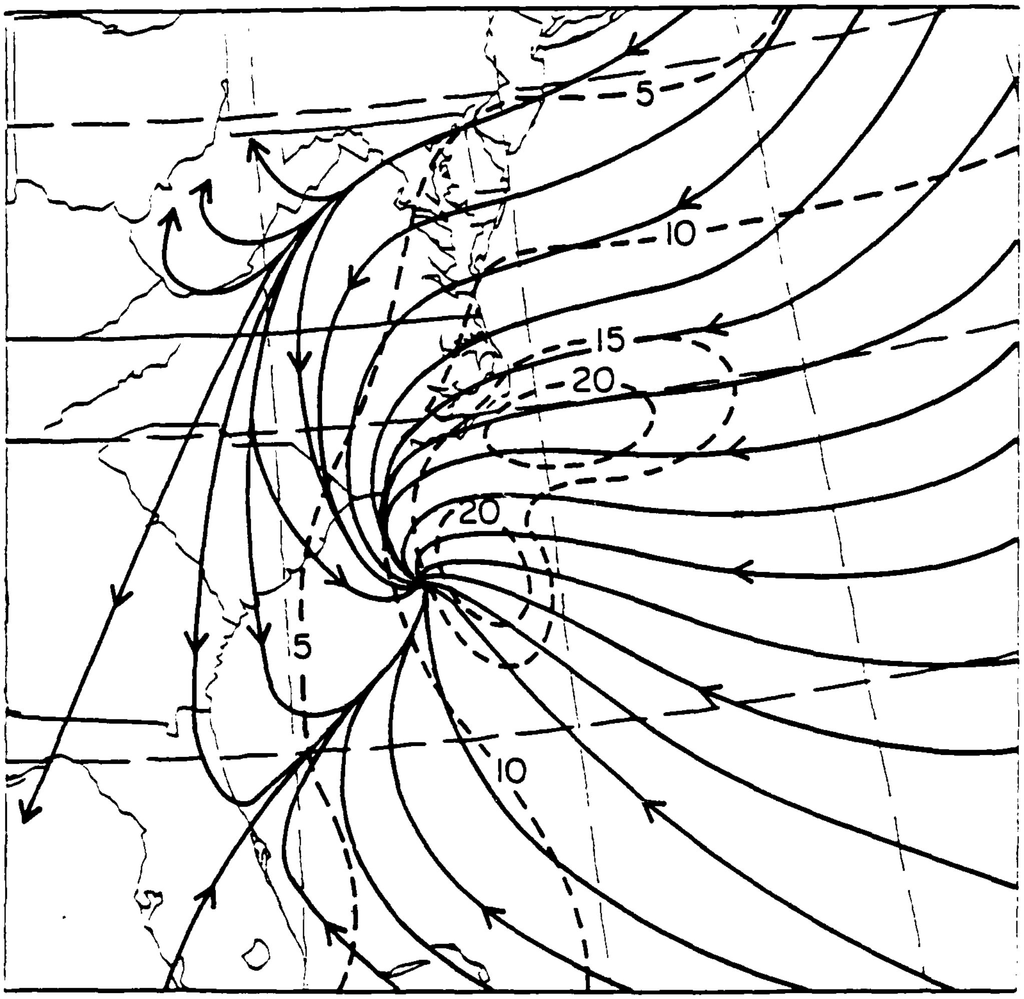


Figure 4.3 Subjective surface streamline (solid) and isotach (dashed) analysis. The isotach contour interval is 5 ms^{-1}.

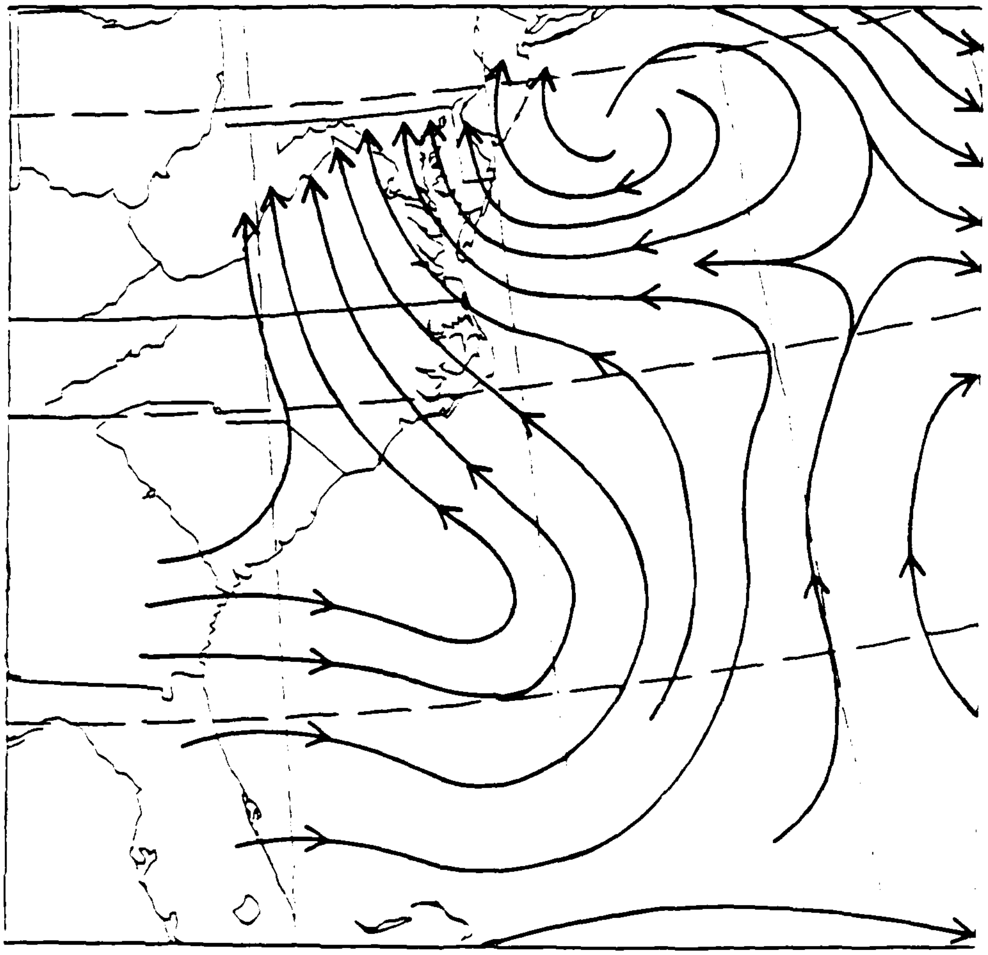


Figure 4.4 Subjective 850 mb streamline analysis.

The sea-level pressure analysis was determined after all surface data were plotted. Enough data was available over both land and ocean to produce a reliable analysis. Figure 4.1 displays the pressure analysis and some of data used. Of particular note is the strength of the wedge ridge east of the Appalachians and the center of the low off the Carolina coast.

A more complicated process was used to determine temperature and moisture data over the Atlantic. Because of the cold anticyclone to the north and the warm sea-surface temperatures in the mid-Atlantic, the thermal structure for the lower levels was assumed to be unstable. Figure 4.5 displays visible satellite imagery for 1800 GMT 18 February 1979, six hours before analysis time. Note the widespread shallow convection at latitudes down to the Carolinas. From this observation, and the existence of the cold air aloft and the warm sea-surface temperatures, it was concluded that the marine boundary layer was likely adiabatic with a uniform mixing ratio up to the lifted condenstion level (LCL) and pseudoadiabatic and saturated above that up to about 850 mb. Above that, the lapse rate again became more stable. Given these assumptions, one can work upward from surface data to define the temperature structure up to at least 900 mb. Thus, to generate data points for the SAs at 1000 mb and the nonstandard levels 950 and 900 mb, soundings were created at the location of ship and buoy data by using

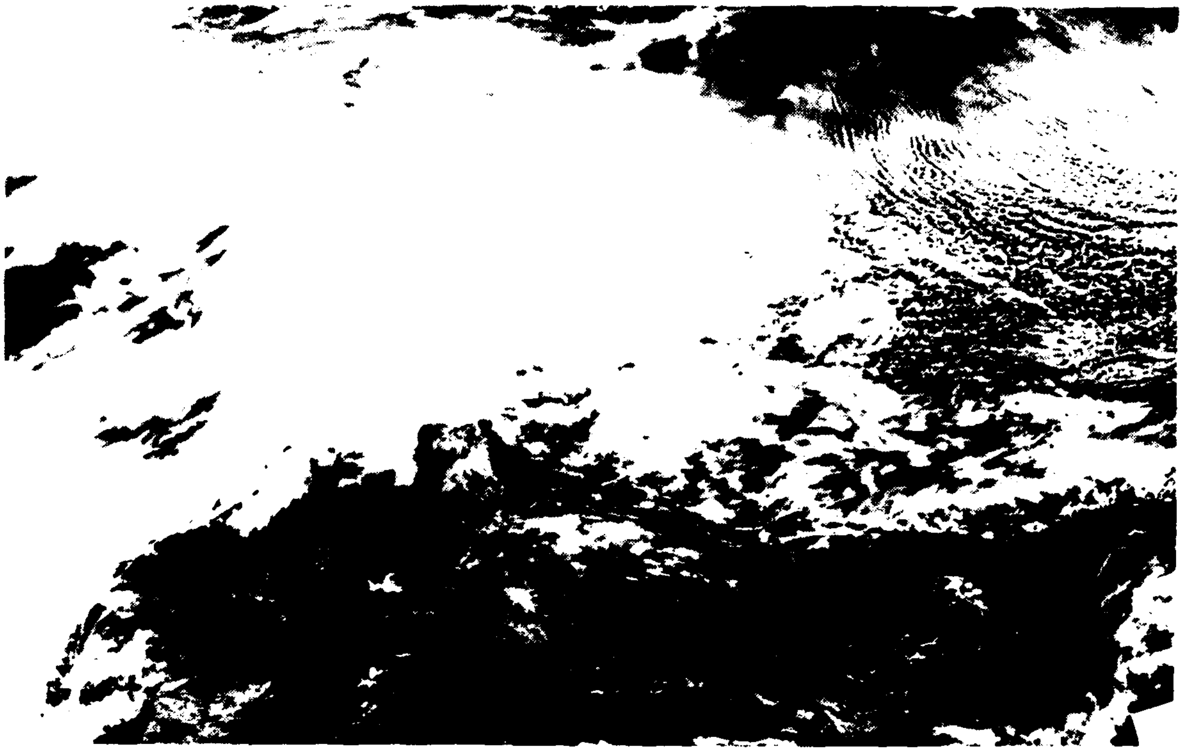


Figure 4.5 Visible satellite imagery for 1800 GMT 18 February 1979.

the reported surface temperature and dewpoint and the assumed lapse rates.

Most continental locations within the domain had acceptable RAWINS/NCAR temperature OAs and were changed very little in the SA. However, subjectively analyzed temperatures are significantly lower than the first guess east of the Appalachians at the surface and at 1000 and 950 mb. This reflects the cold air damming, evident by the wedge ridge in the sea-level pressure, shown in Figure 4.1. Proper representation of this feature in the temperature field was necessary to achieve acceptable geopotential heights at higher levels. The pressure ridge would have been reflected in a geopotential-height ridge aloft if its cause, the pool of low-level, cold, dense air trapped against the mountains, was not represented in the analyses.

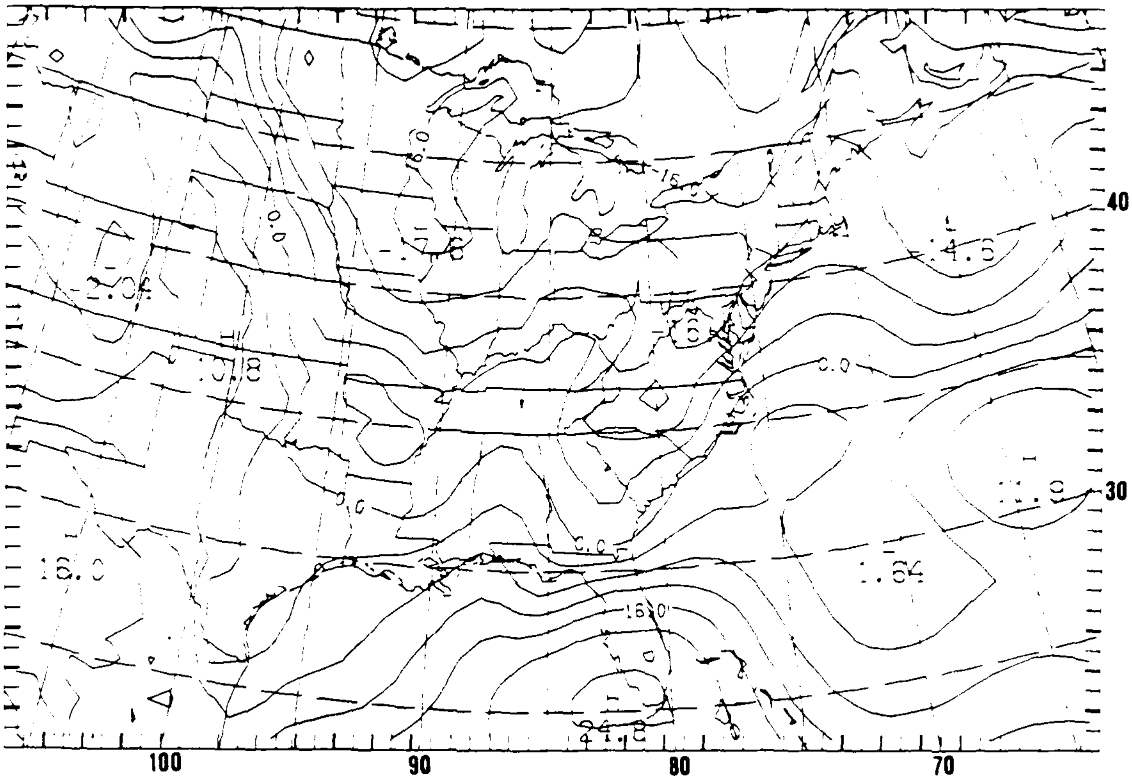
SAs of moisture fields were not explicitly performed, except the surface dewpoint depression (not shown). The RAWINS/NCAR fields were uniformly moist at low levels, which was consistent with the satellite imagery indicating widespread shallow convection. Because of this, little attention was given to these fields.

SAs of winds were more difficult and actually were not attempted, except at the surface, the only level where adequate data was available, and at 850 mb, where analysis was guided by analyzed geopotential heights. The surface streamline and isotach analysis is shown in Figure 4.3. Figure 4.4 shows subjectively analyzed streamlines at 850 mb.

4.2 Comparisons of SAs with RAWINS/NCAR-Produced First-Guess Fields

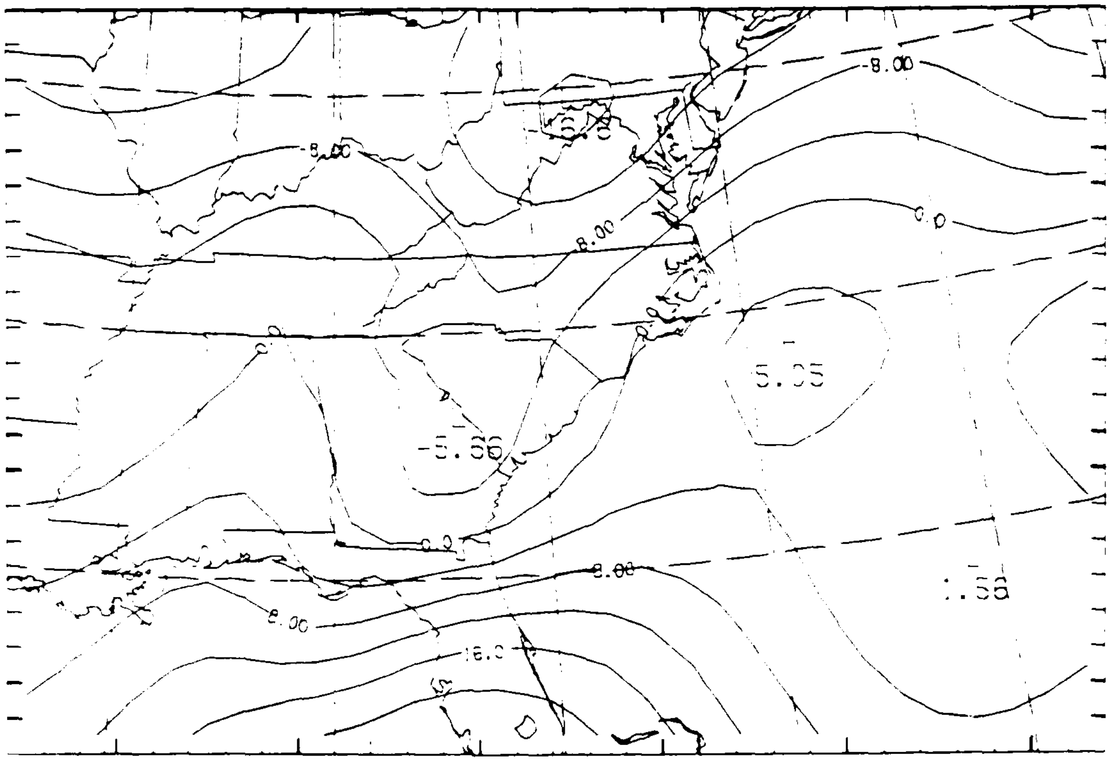
Figures 4.6 through 4.9 show the first-guess OA fields at low levels produced by RAWINS/NCAR. The first guess for RAWINS/NCAR comes from NMC's archived analyses, and the only data source for the RAWINS/NCAR analysis was the 0000 GMT 19 February 1979 radiosonde network data. Of note are the poor sea-level pressure analysis, shown in Figure 4.8, the extremely poor quality of temperature analyses at the surface, 1000, and 950 mb, and the consequent poor geopotential height analyses. By comparing the SA of sea-level pressure in Figure 4.1 to the OA in Figure 4.8, it is seen that the most notable difference is the lack of a well-defined surface low off the Carolina-Georgia coast in the RAWINS/NCAR OA. Where there is a closed low with a 1017 mb central pressure, the RAWINS/NCAR field has only an open wave with a 1022 mb pressure. Similarly, the wedge ridge resulting from the cold air damming east of the Appalachians is underrepresented in the OA. For example, the 1028 mb contour lies as far south as Georgia in the SA but reaches only to northernmost South Carolina in the OA.

The temperature analyses at the surface, 1000 mb, and 950 mb are also poor, being too cold over the ocean and too warm in the damming region. This presumably resulted from the lack of data and the inability of the OA to assimilate

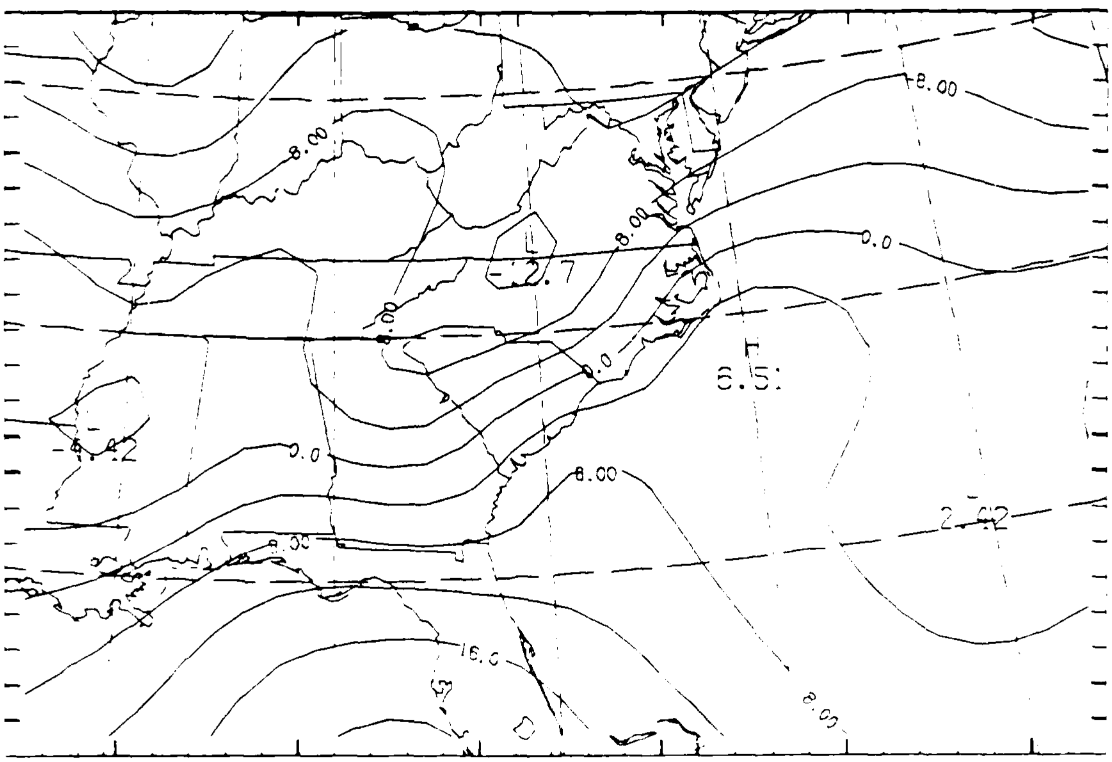


(a) surface

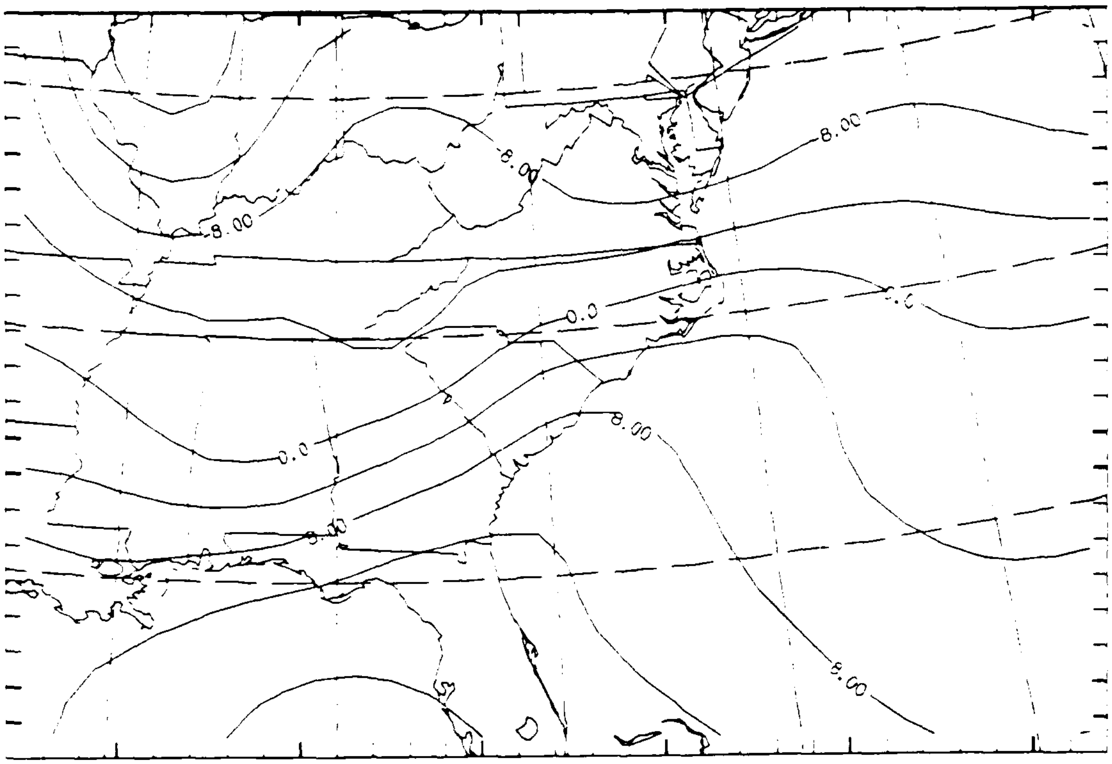
Figure 4.6 RAWINS/NCAR-produced temperature analyses for (a) surface, (b) 1000 mb, (c) 950 mb, (d) 900 mb, and (e) 850 mb. The contour interval is 4C.



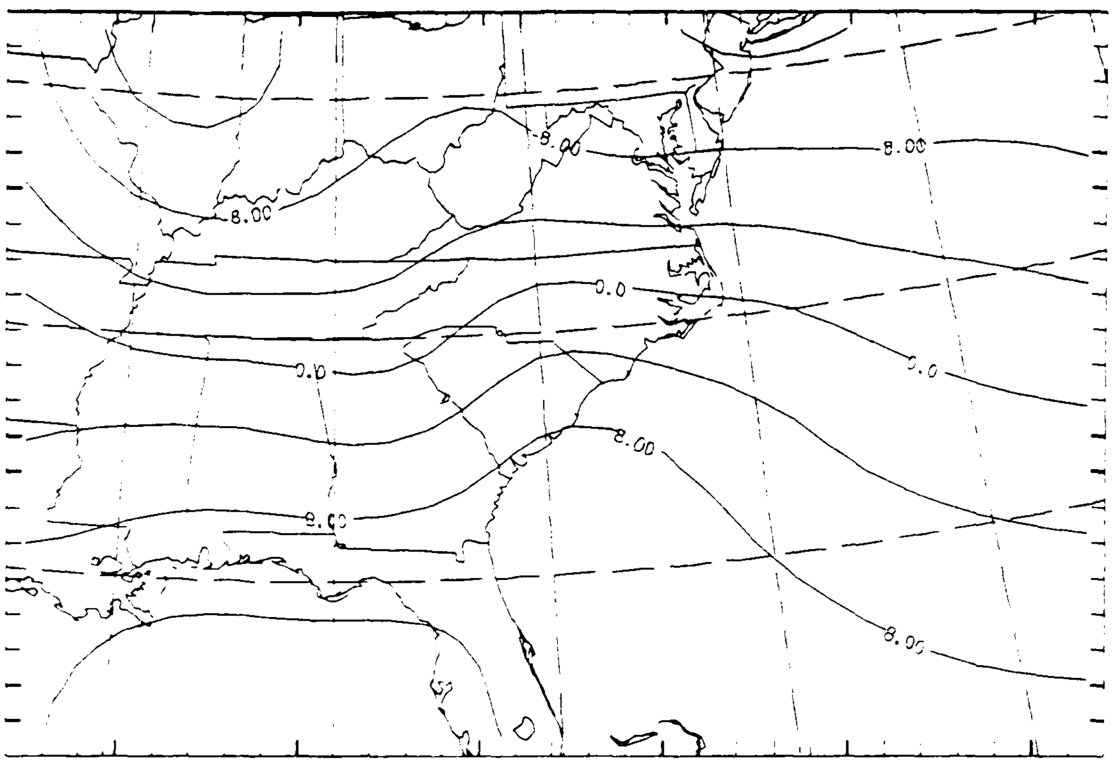
(b) 1000 mb



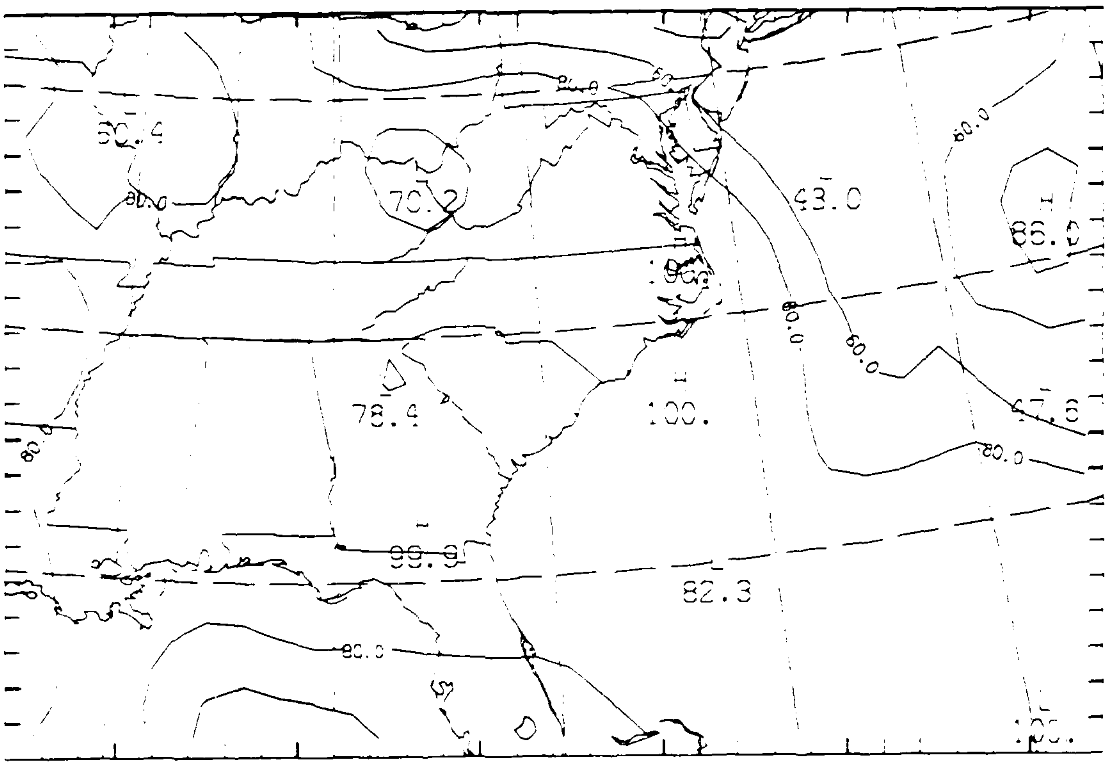
(c) 950 mb



(d) 900 mb

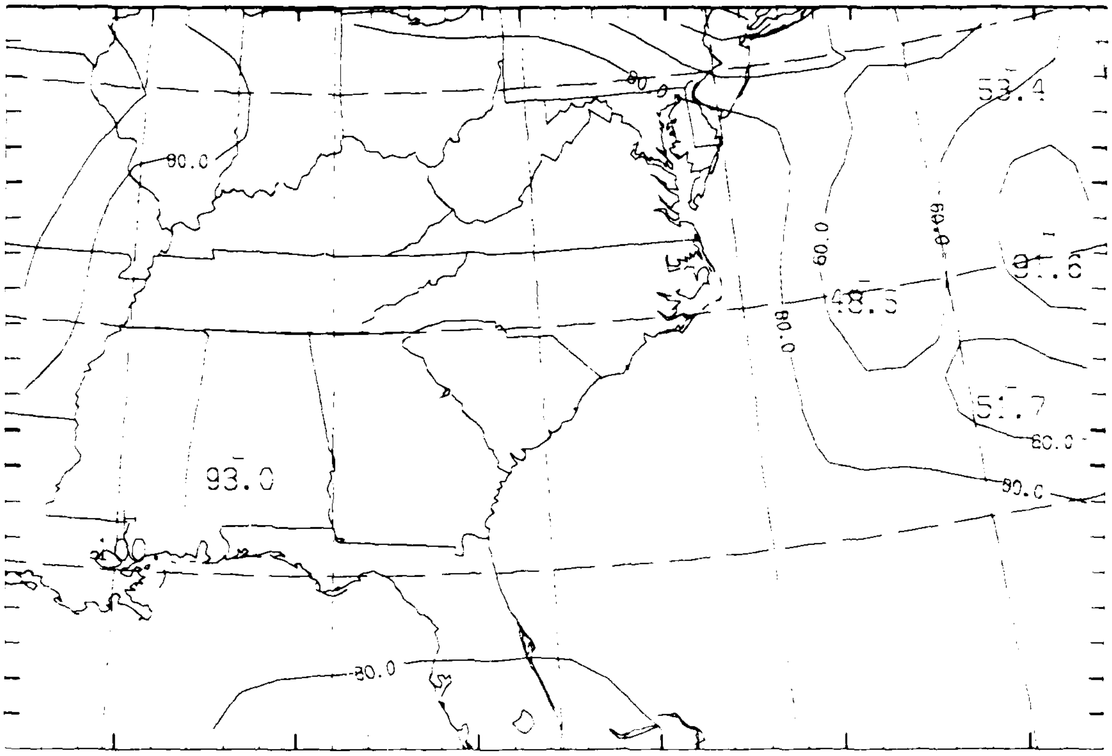


(e) 850 mb

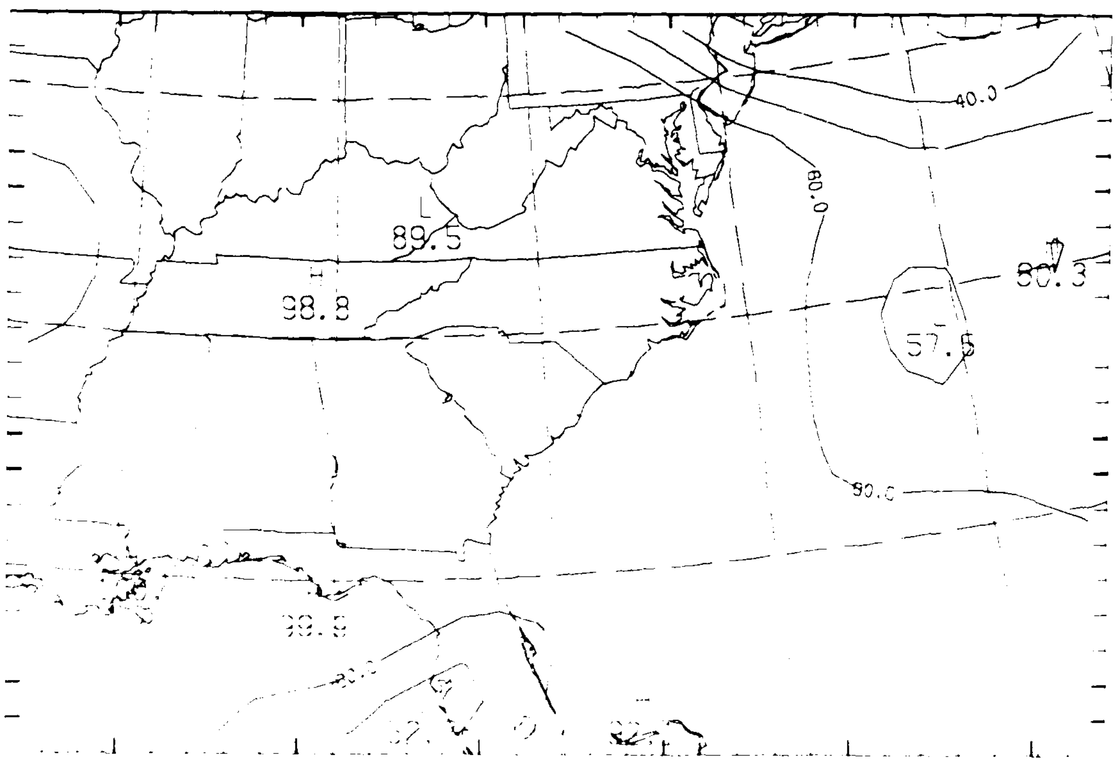


(a) surface

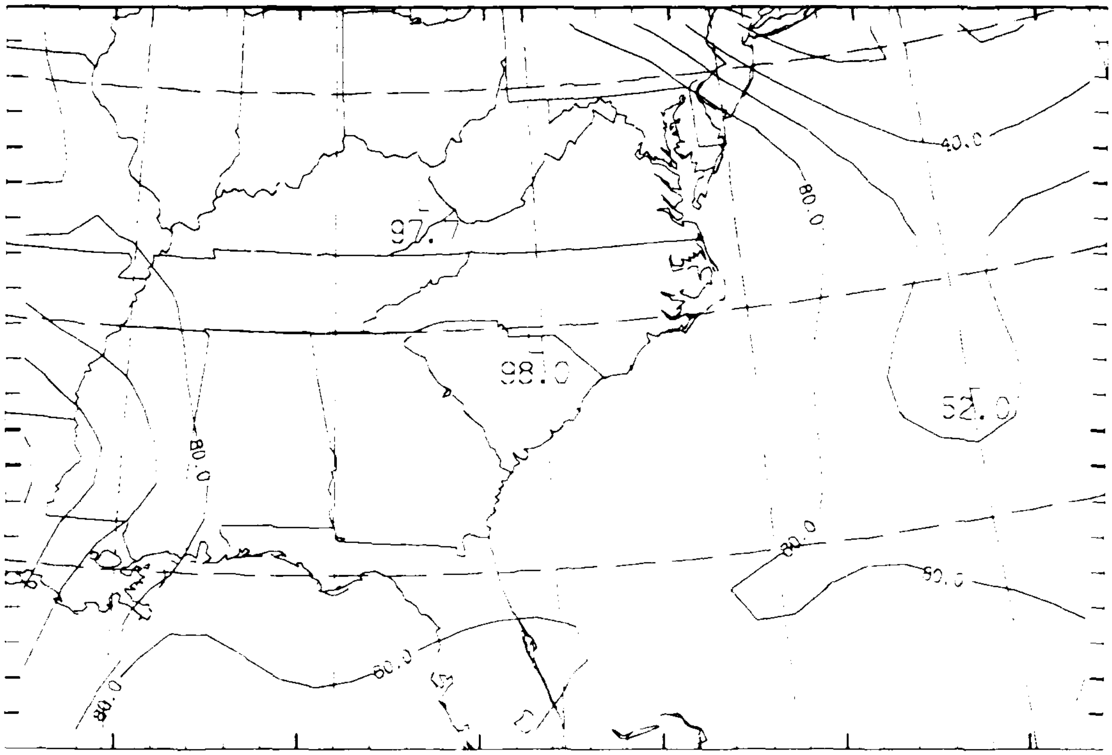
Figure 4.7 RAWINS/NCAR-produced relative humidity analyses for (a) surface, (b) 1000 mb, (c) 950 mb, (d) 900 mb, and (e) 850 mb. The contour interval is 20 percent.



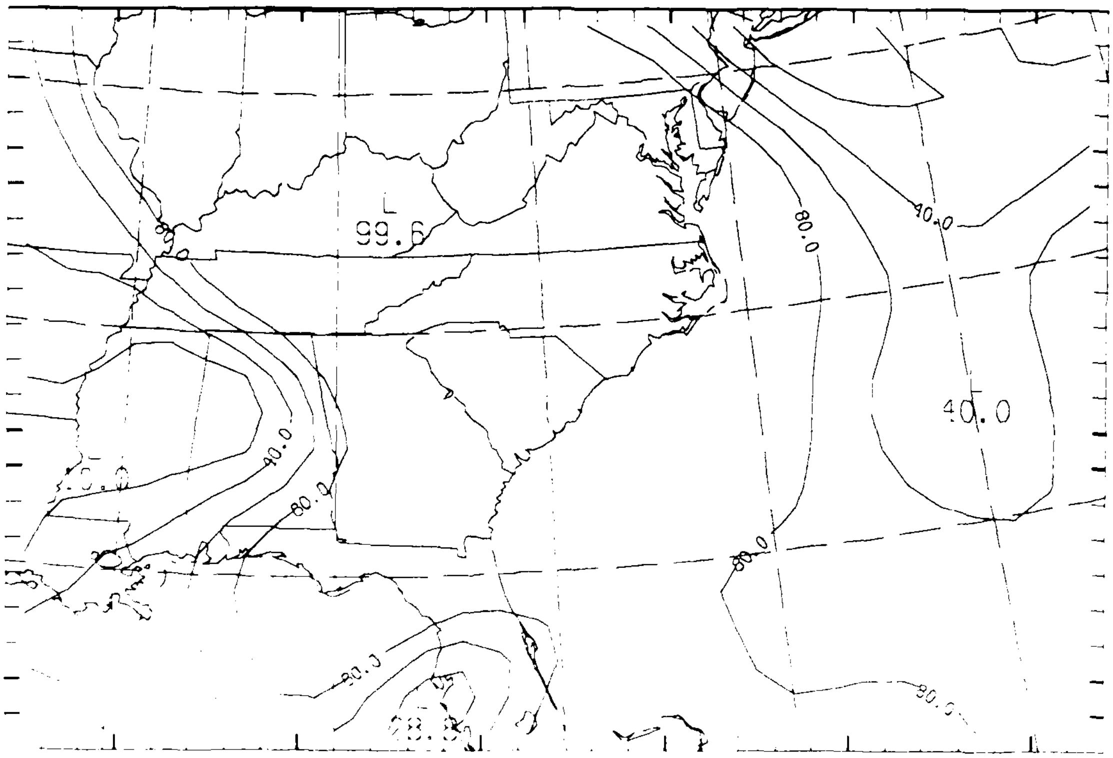
(b) 1000 mb



(c) 950 mb



(d) 900 mb



(e) 850 mb

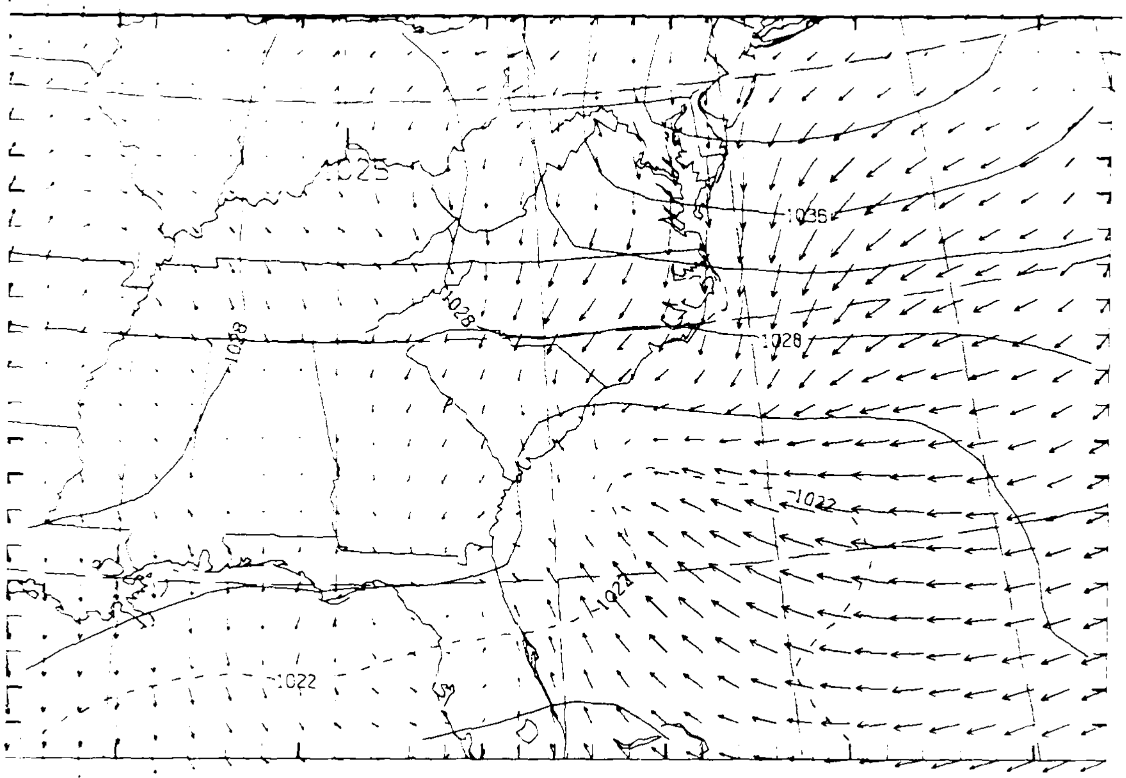
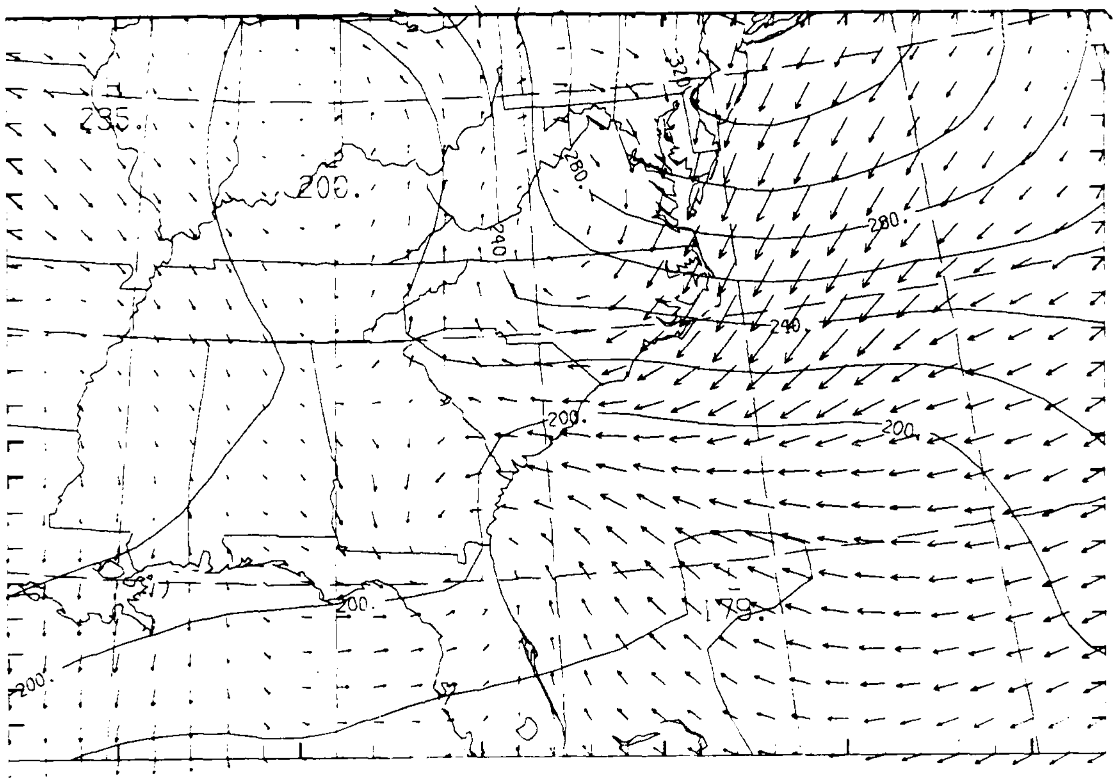
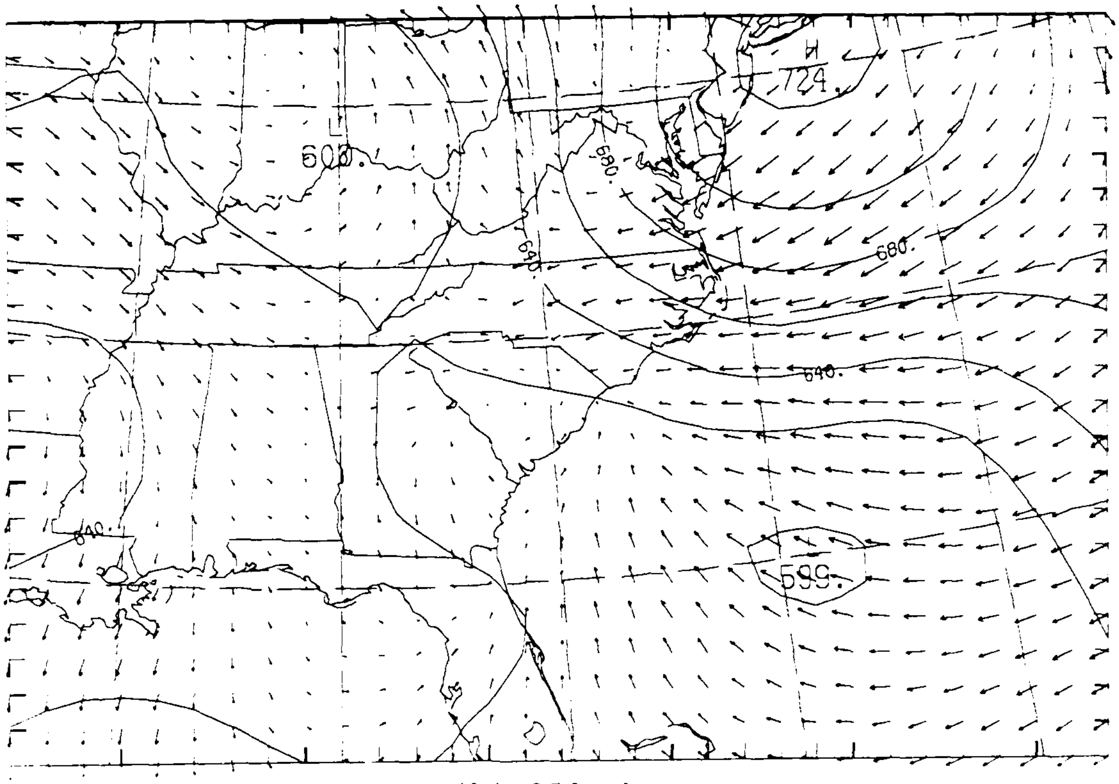


Figure 4.8 RAWINS/NCAR-produced analyses of sea-level pressure and surface wind. A vector 1 grid interval in length (⟼) is 20 ms^{-1}. The contour interval for pressure is 4 mb.

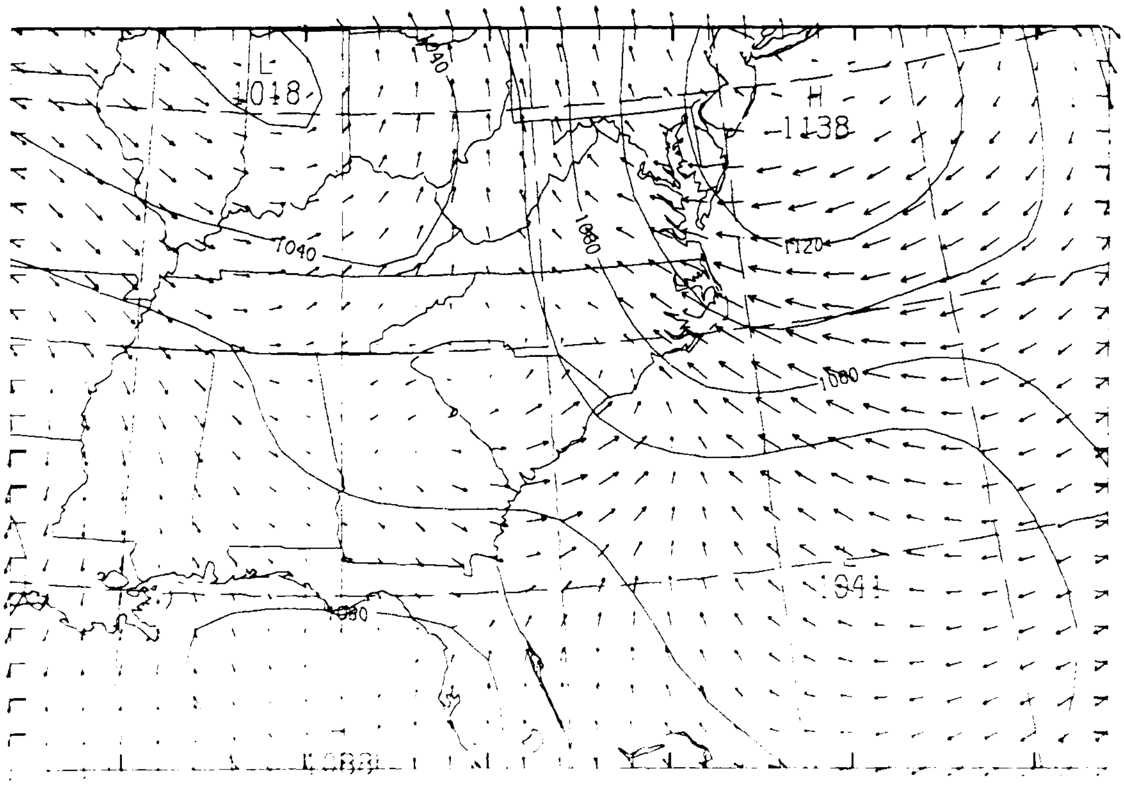


(a) 1000 mb

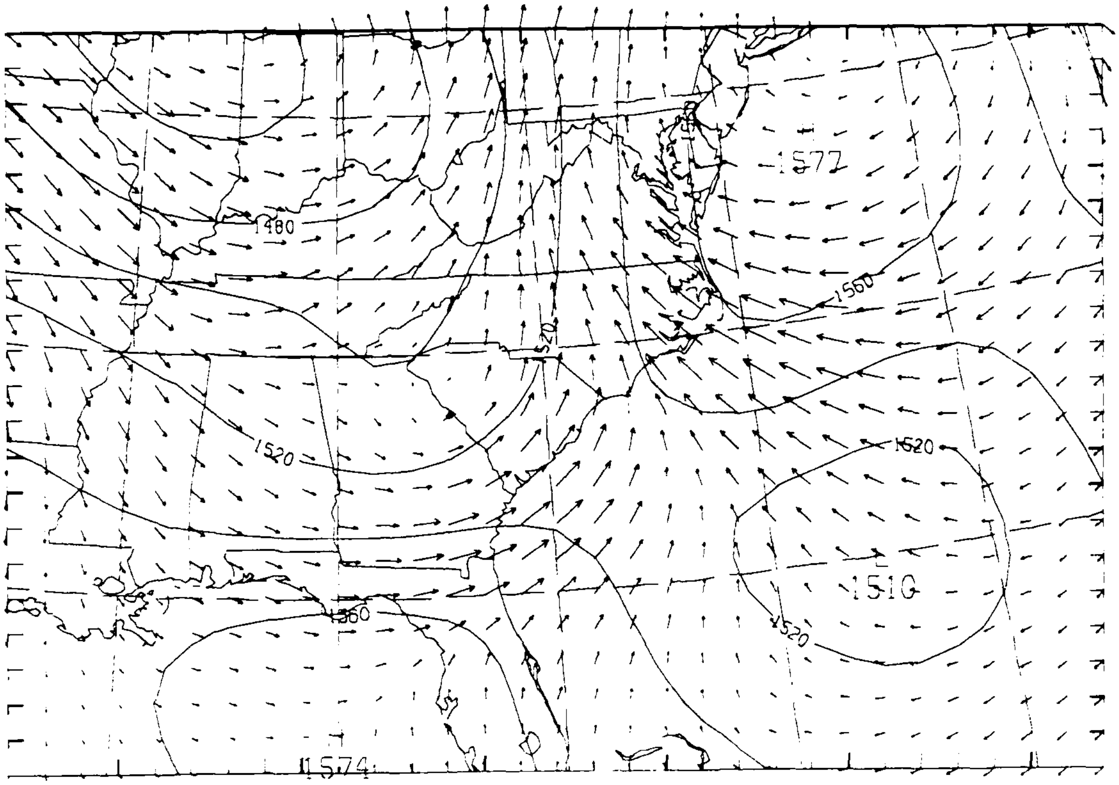
Figure 4.9 RAWINS/NCAR-produced analyses of geopotential height and wind for (a) 1000 mb, (b) 950 mb, (c) 900 mb, (d) 850 mb, and (e) 700 mb. A vector 1 grid interval in length (⟼) is 20 ms^{-1}. The contour interval for geopotential height is 20 m.



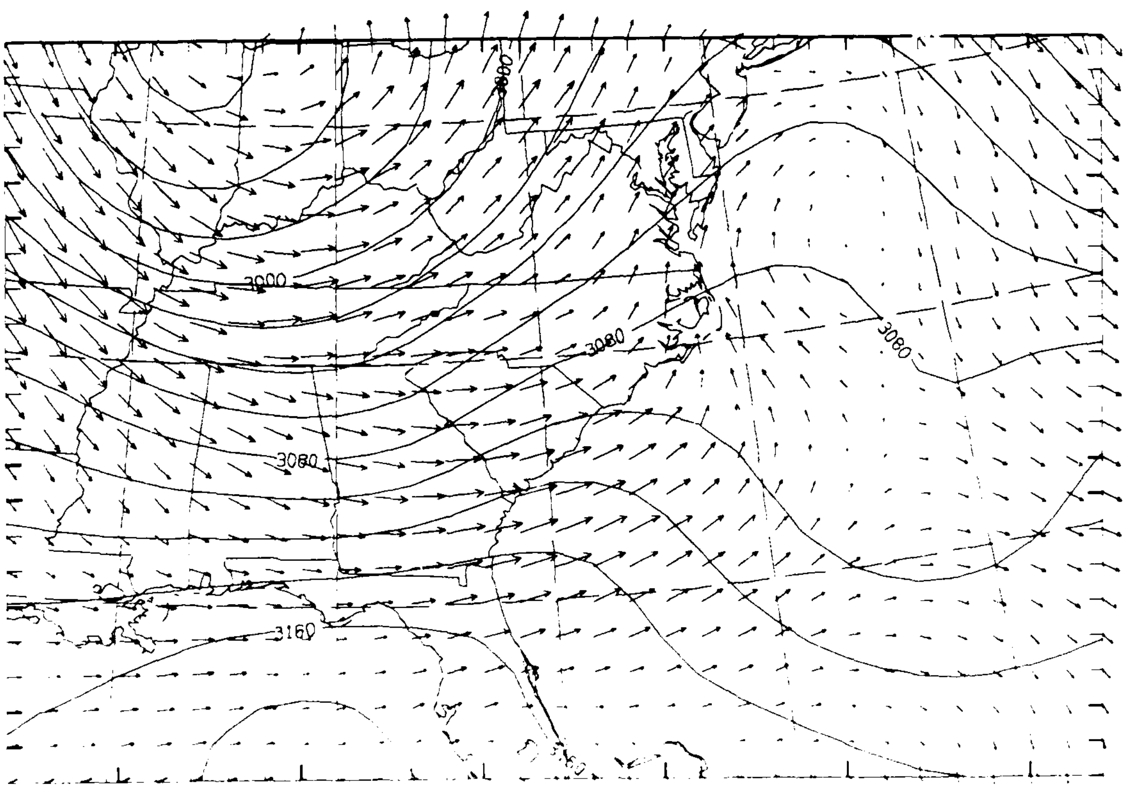
(b) 950 mb



(c) 900 mb



(d) 850 mb



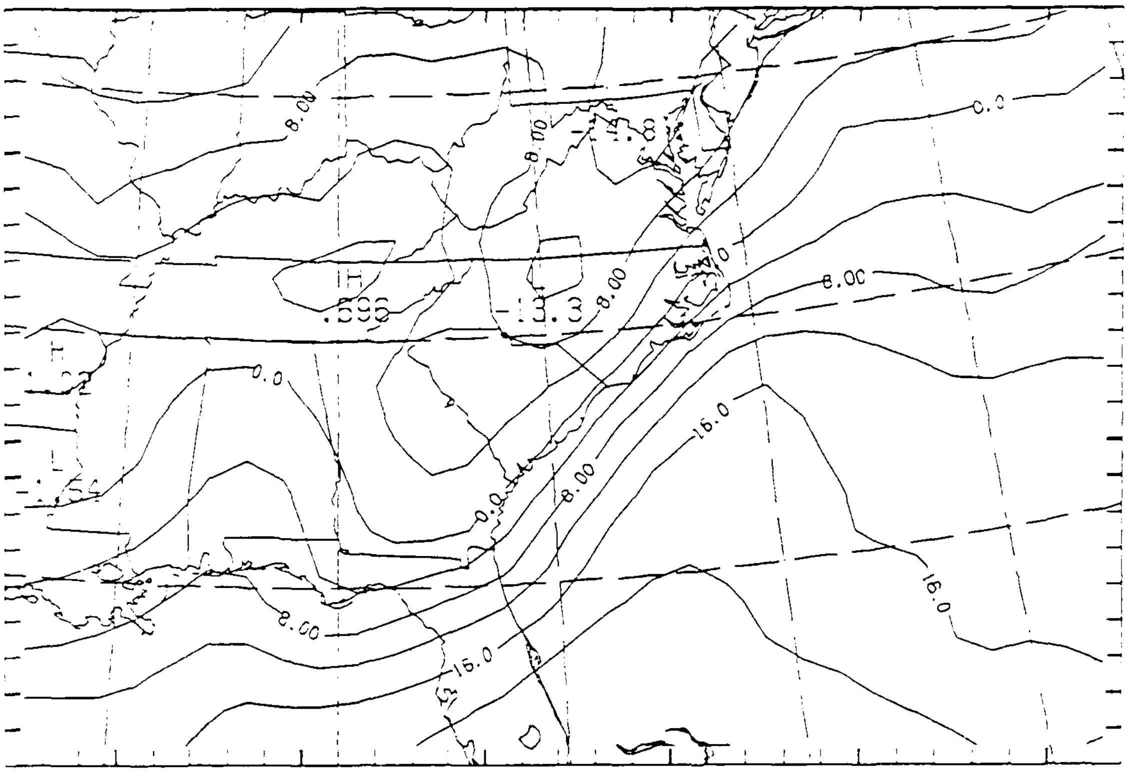
(e) 700 mb

and properly use what sparse ship data existed. Further from the coast, the deviation between the SA and the first guess worsens, the OA being nearly 15C too cold at 30N,70W. Comparing the 850 mb SA in Figure 4.2e to the OA in Figure 4.6e, note that the OA differs very little from the SA. Since there was no reasonable way of determining inaccuracies above 850 mb, the assumed top of the shallow convection, SAs were not attempted and no bogusing was done.

There were also discrepancies between the wind analyses, as noted by comparing the SAs in Figures 4.3 and 4.4 to the OAs in Figure 4.8 and 4.9. The OAs lack the low-level cyclonic circulation evident in the surface streamline analysis, while at 850 mb the subjective streamline analysis also differs considerably from the OA analysis.

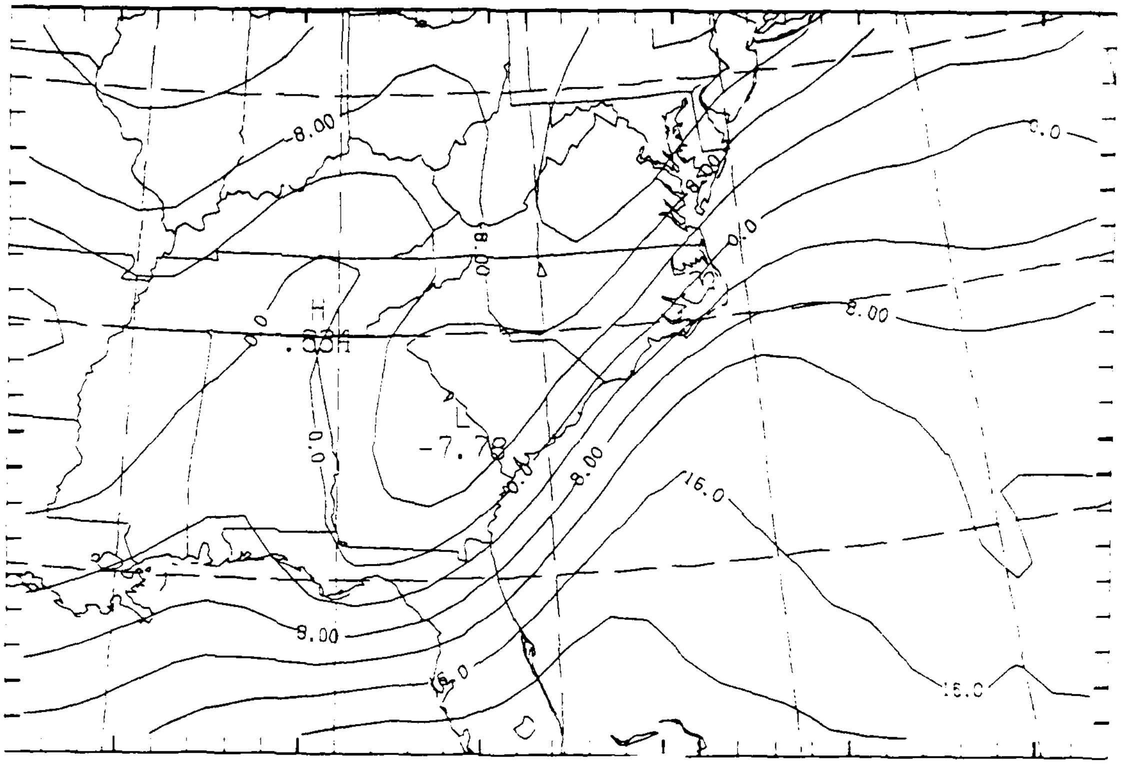
4.3 RAWINS/PSU-Produced Objective Analyses

Using the interactive bogusing software, an improved set of initial conditions was developed for the regions with the worst first guess fields. These new analyses are displayed in Figures 4.10 through 4.13. Figure 4.10 shows the temperature analyses, and Figure 4.11 shows the relative humidity analyses. Figures 4.12 and 4.13 show wind analyses. Following is a discussion of the technique used to produce these analyses and its limitations.

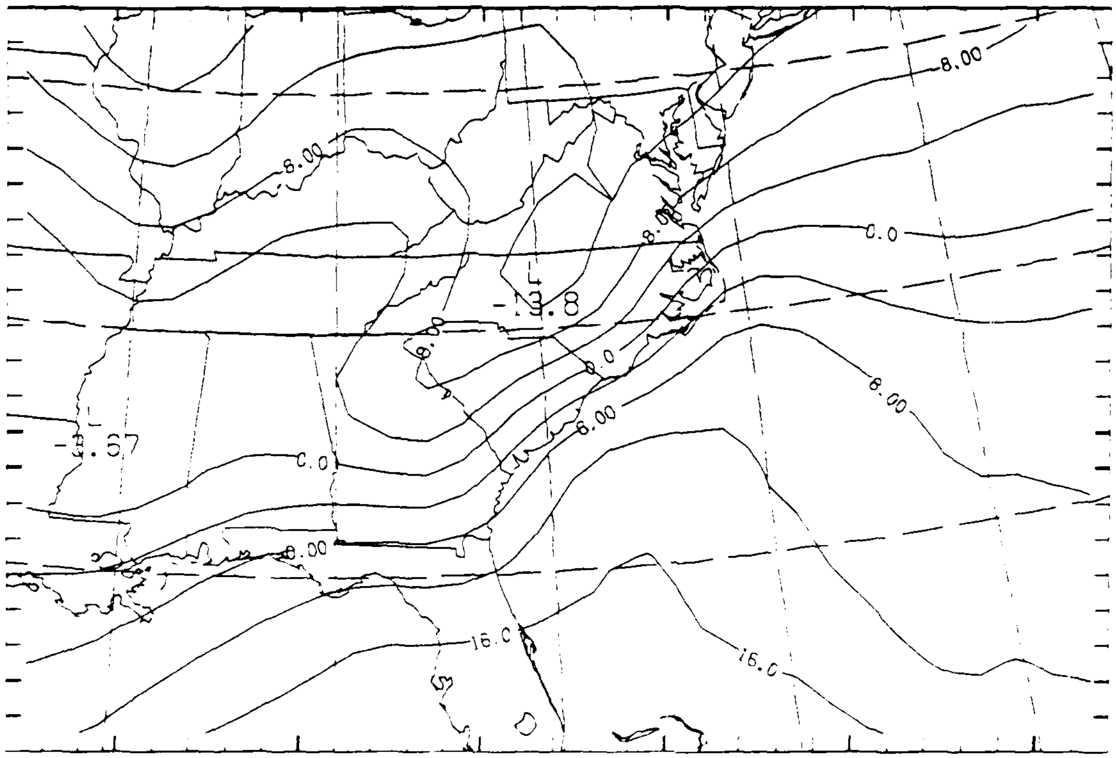


(a) surface

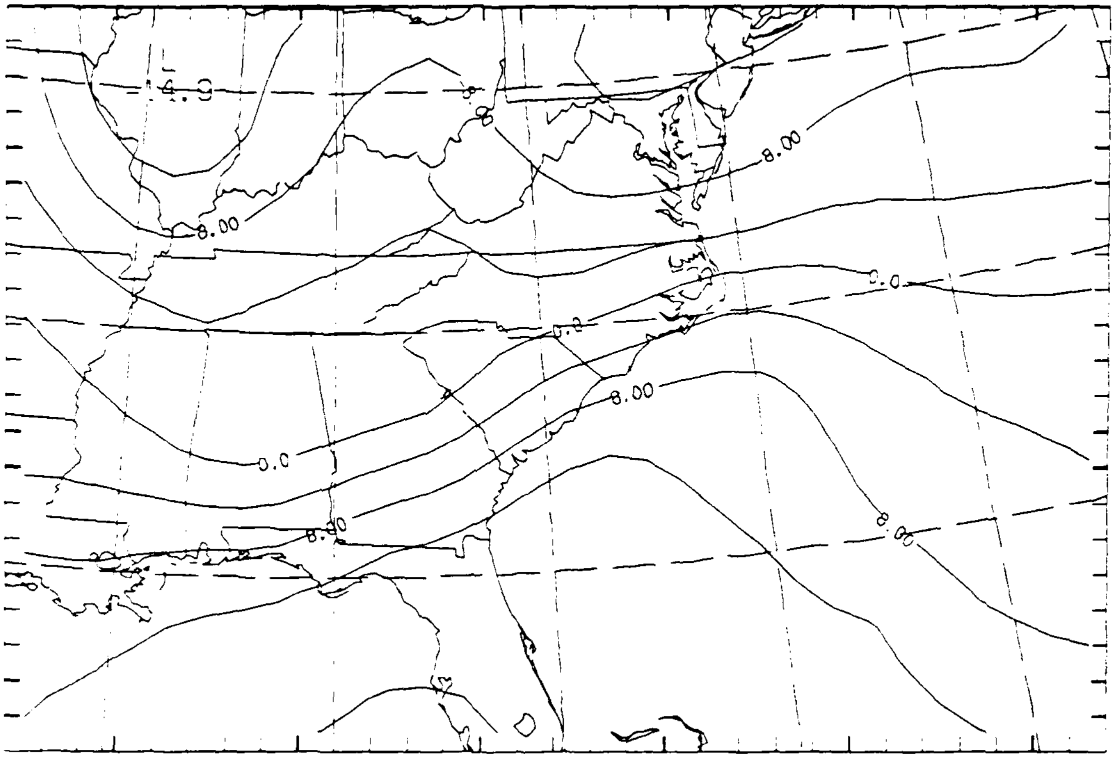
Figure 4.10 RAWINS/PSU-produced temperature analyses for (a) surface, (b) 1000 mb, (c) 950 mb, (d) 900 mb, and (e) 850 mb. The contour interval is 4C.



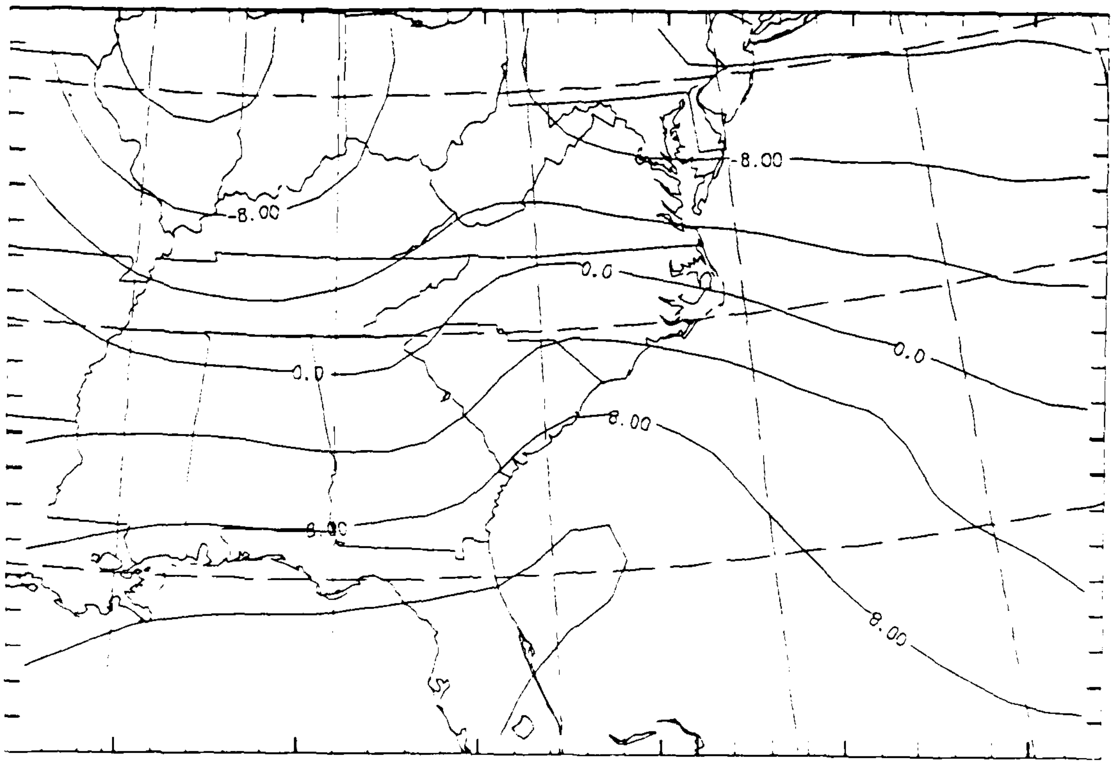
(b) 1000 mb



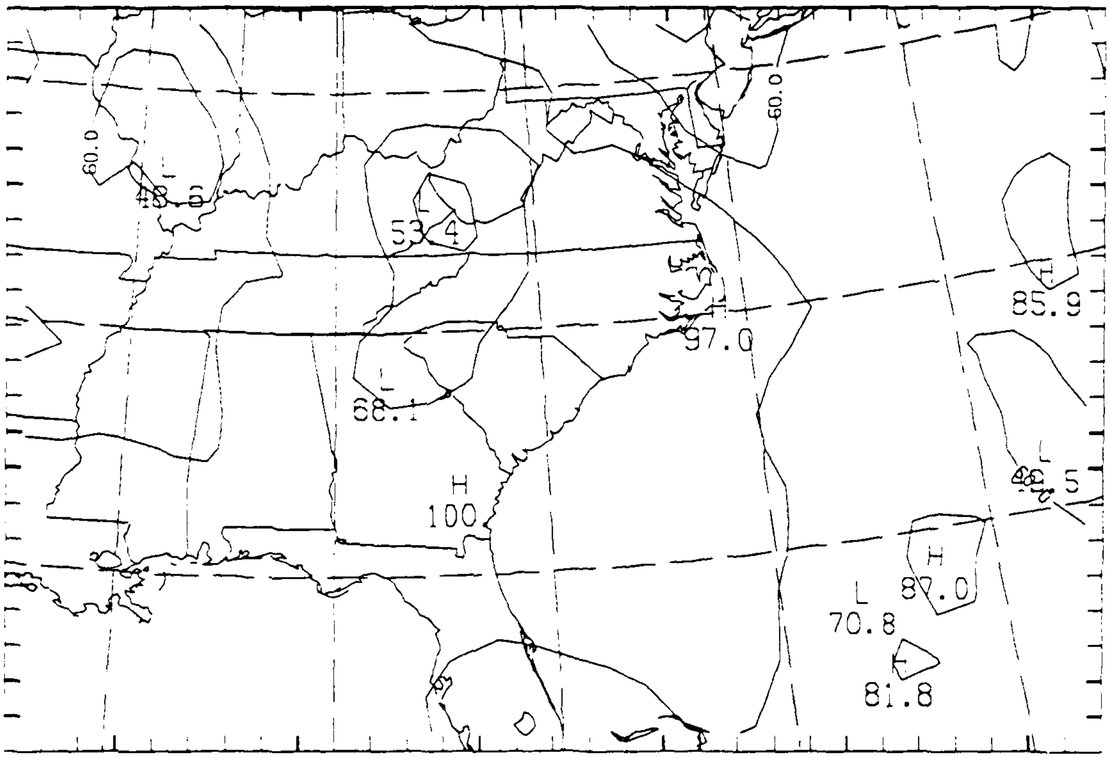
(c) 950 mb



(d) 900 mb

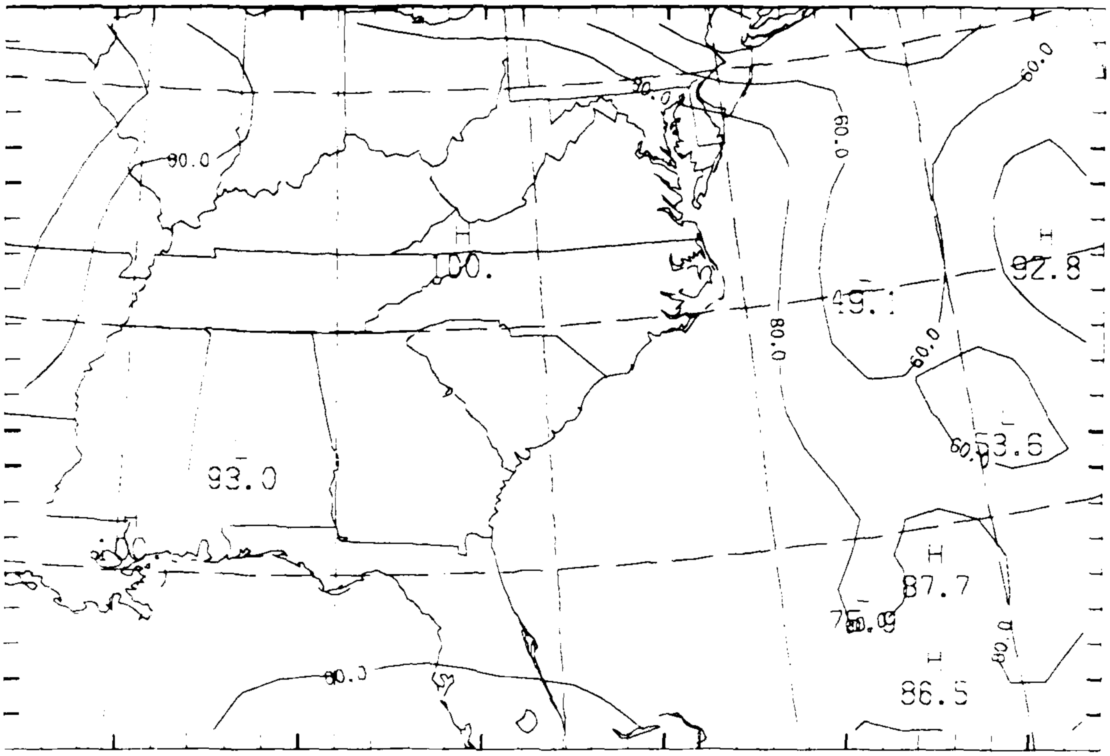


(e) 850 mb

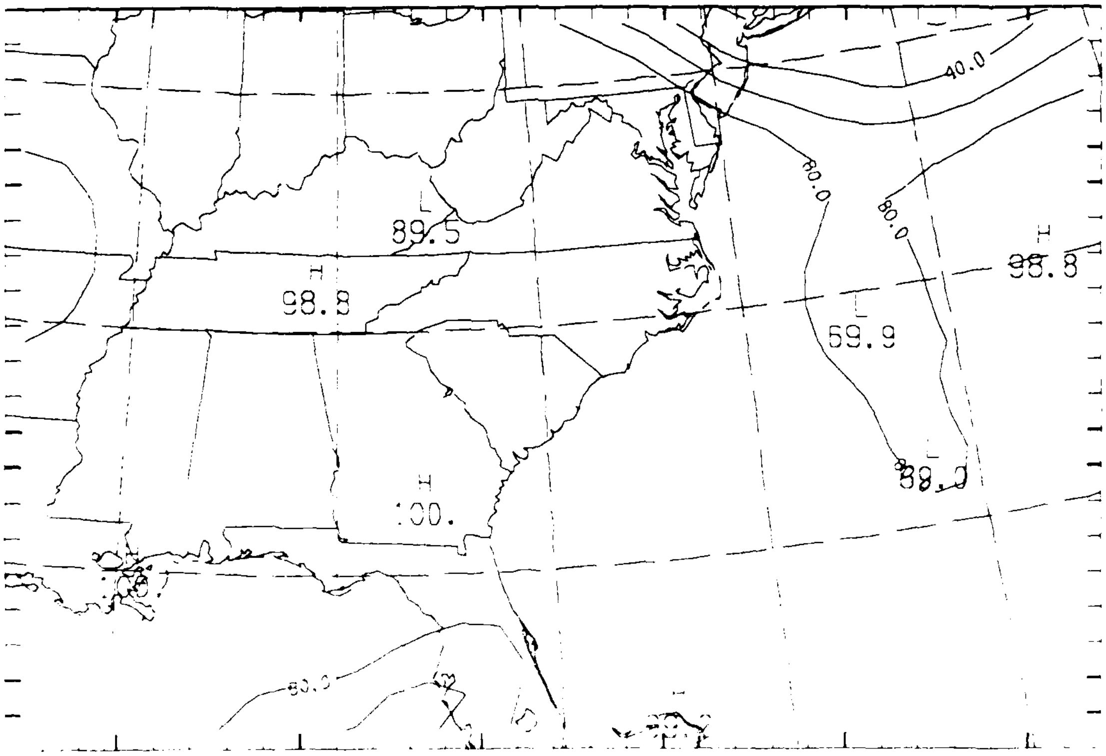


(a) surface

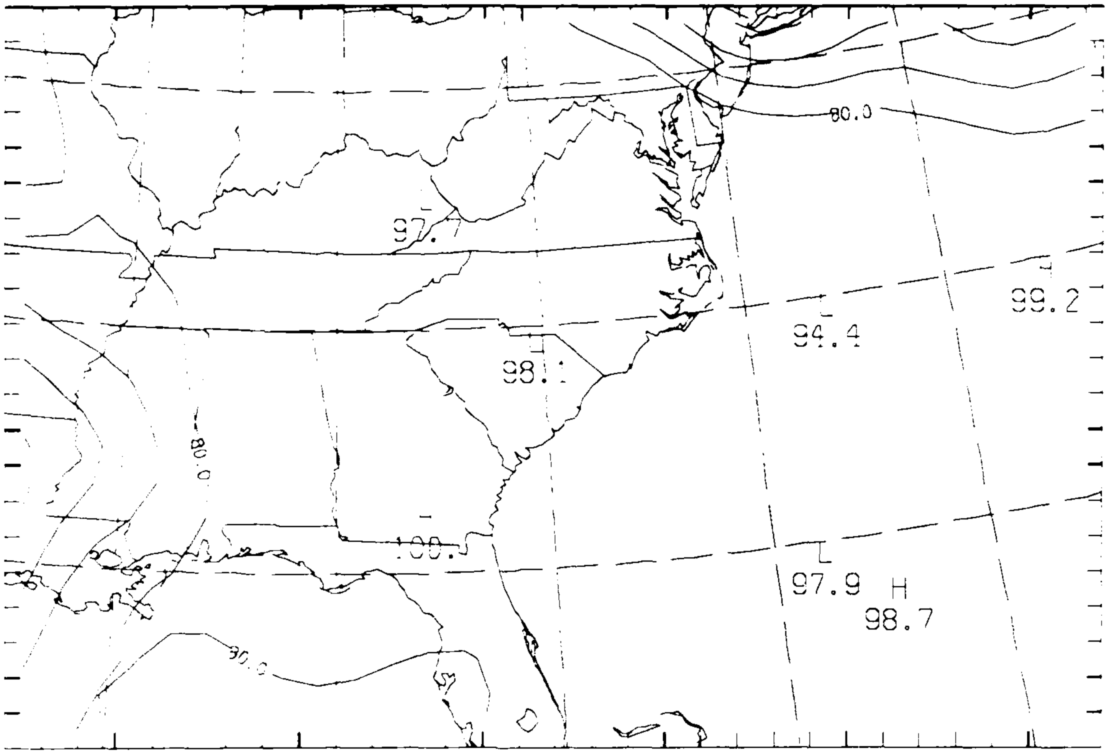
Figure 4.11 RAWINS/PSU-produced relative humidity analyses for (a) surface, (b) 1000 mb, (c) 950 mb, (d) 900 mb, and (e) 850 mb.



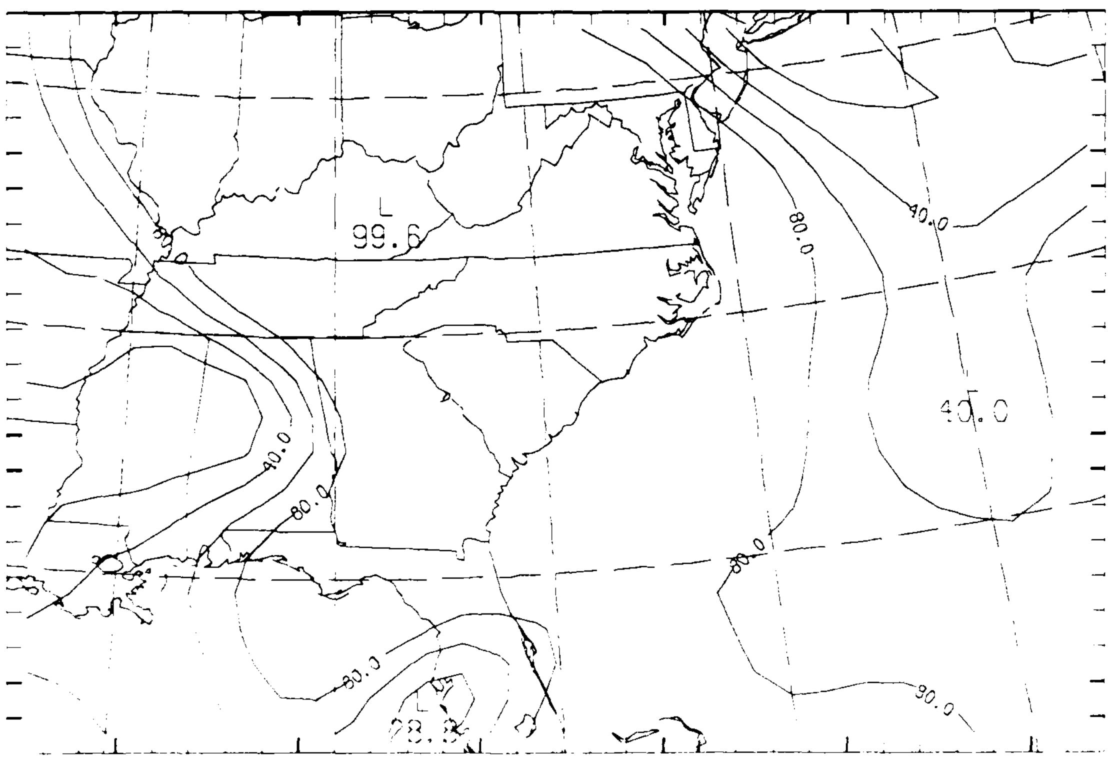
(b) 1000 mb



(c) 950 mb



(d) 900 mb



(e) 850 mb

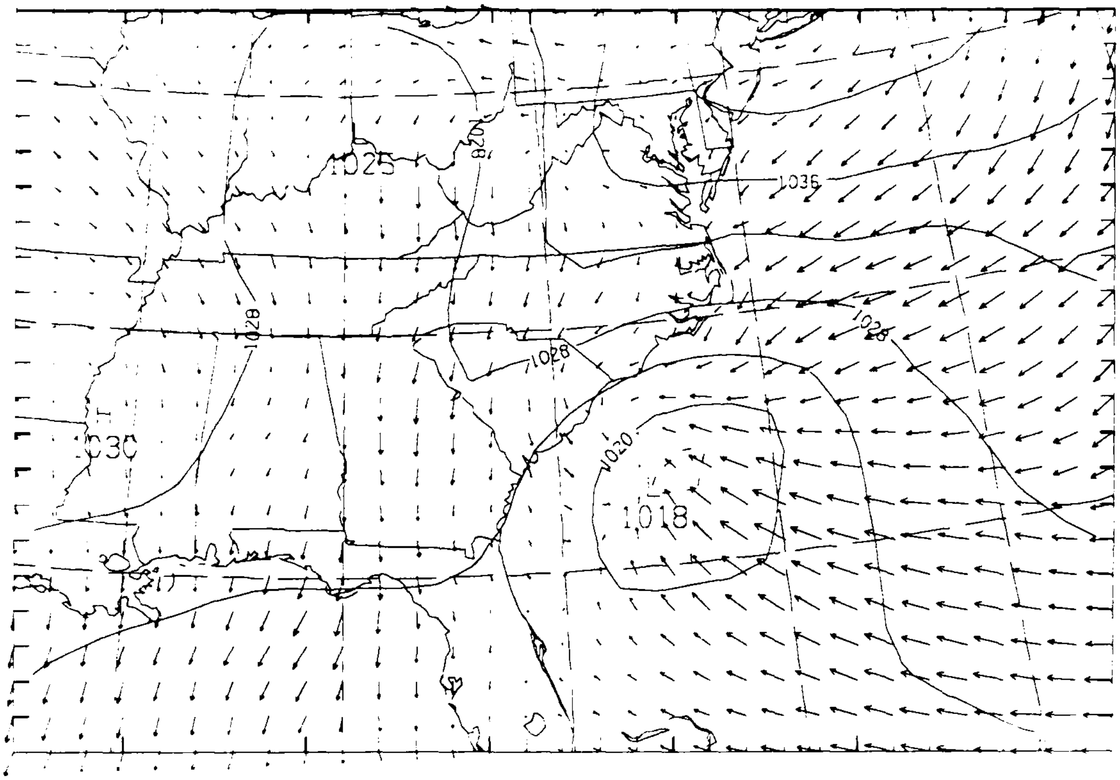
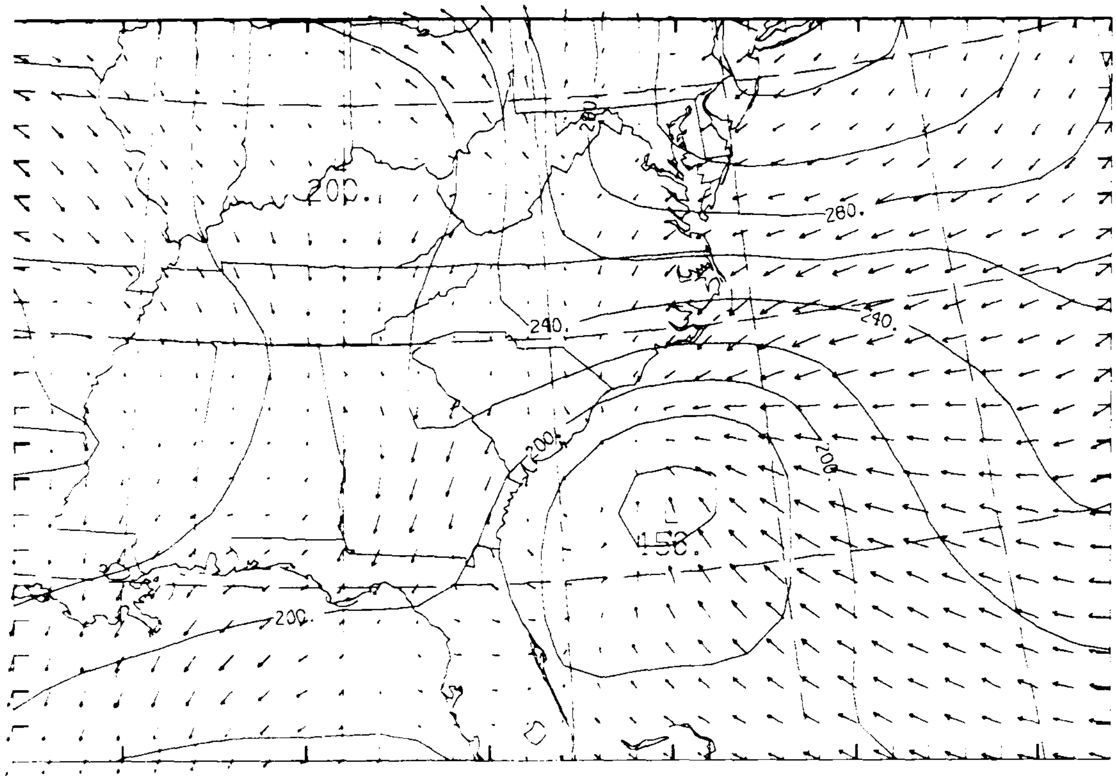
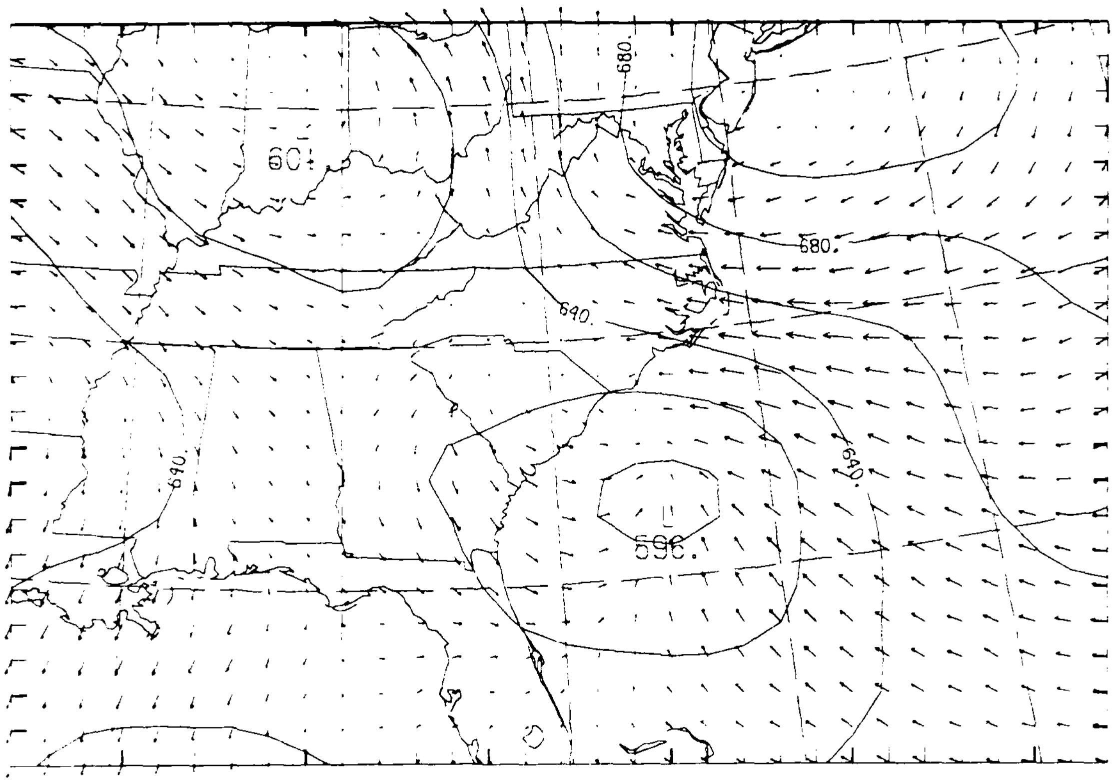


Figure 4.12 RAWINS/PSU-produced sea-level pressure and surface wind analyses. A vector grid interval in length (⟼) is 20 ms^{-1}. The contour interval for pressure is 4 mb.

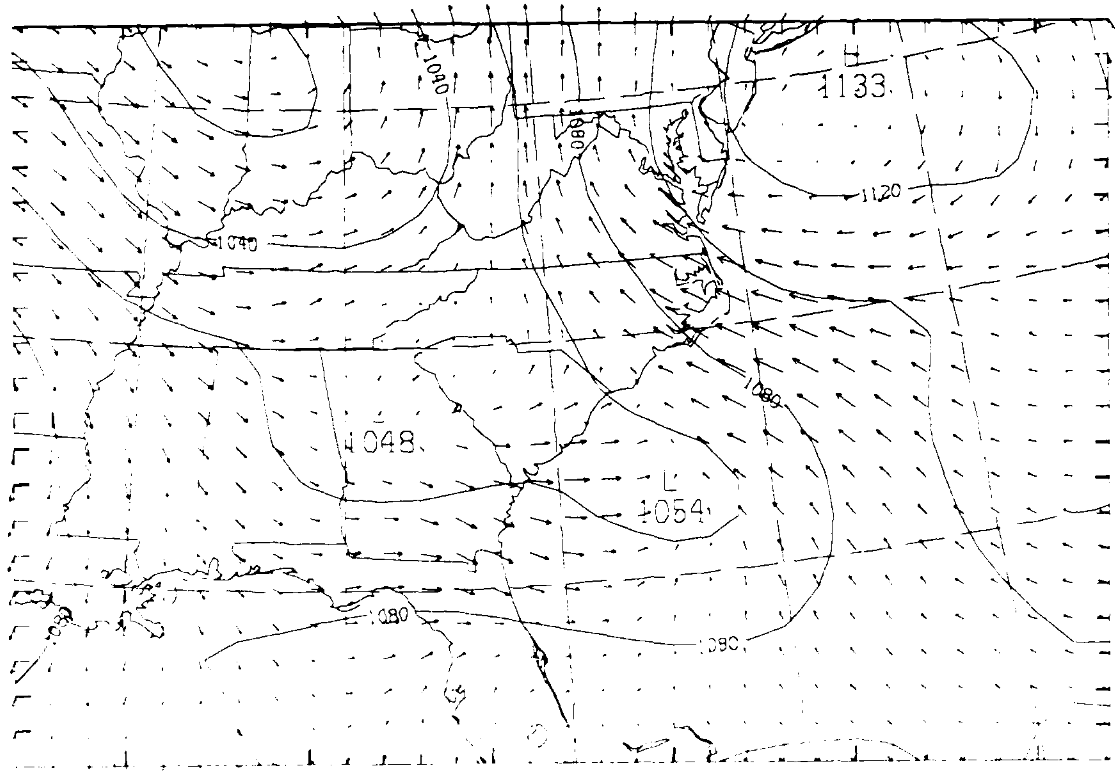


(a) 1000 mb

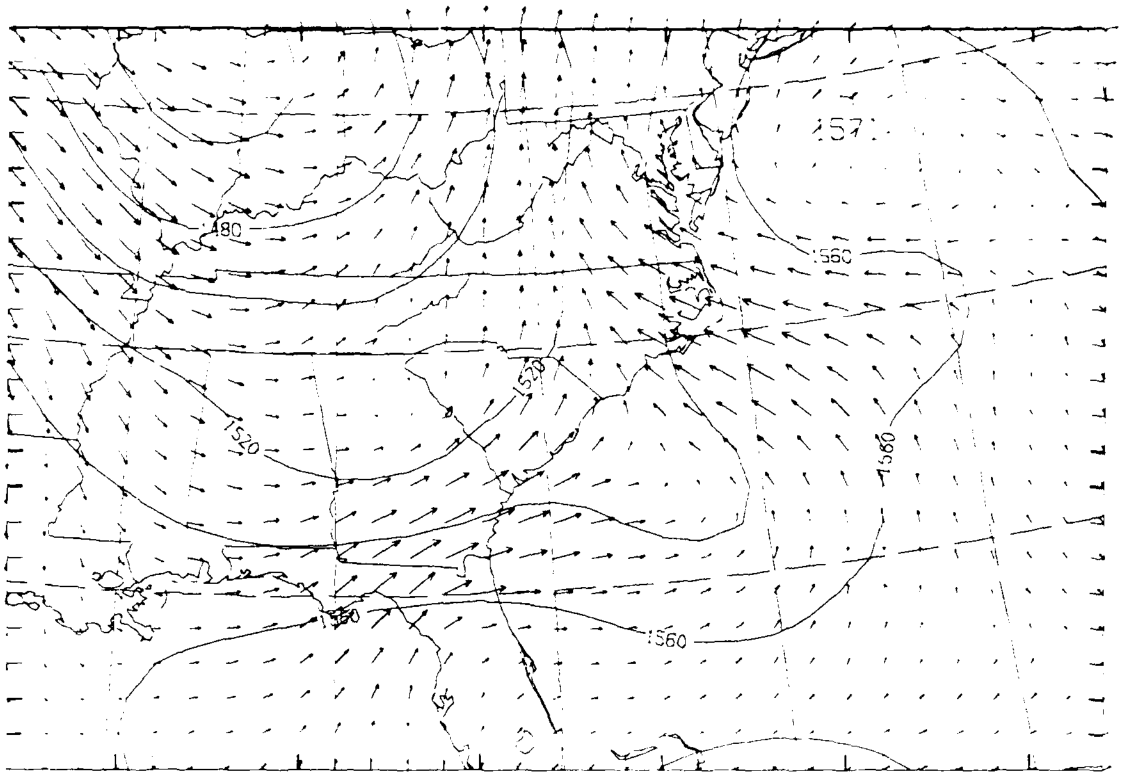
Figure 4.13 RAWINS/PSU-produced analyses of geopotential heights and wind for (a) 1000 mb, (b) 950 mb, (c) 900 mb, (d) 850 mb, and (e) 700 mb. A vector 1 grid interval in length (→) is 20 ms^{-1}. The contour interval for geopotential height is 20 m.



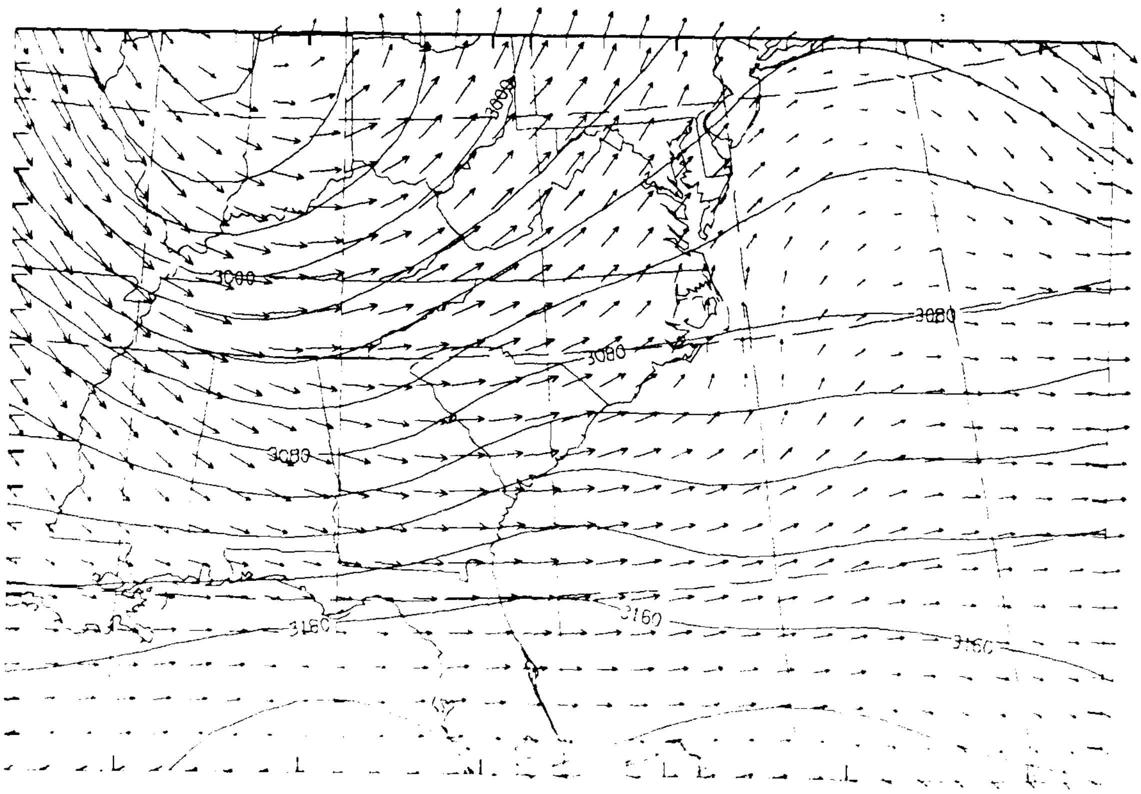
(b) 950 mb



(c) 900 mb



(d) 850 mb



(e) 700 mb

4.3.1 A Discussion of the Bogusing Technique

Producing quality initial conditions for this case was a great challenge due to the poor OAs of the low-level temperature and wind. As noted before, a large expanse of ocean area had first-guess temperatures that were 10 to 15C too cold and unrealistic wind analyses. Because of the magnitude of the difference between the first guess and the SA, and because the successive-correction scheme in such a case cannot produce a good analysis with only a few observations, many supplemental bogus soundings were needed over the region in question to achieve an analysis with good horizontal consistency. Figure 4.6a, the surface-temperature OA, exhibits the problem created when the observations are widely spaced. In this RAWINS/NCAR-produced OA, the temperature analysis in a small area around the Bermuda rawinsonde station (32N,64W) is relatively accurate. However, with increasing distance from Bermuda, temperatures rapidly decrease to unrealistic values, since no observations were available in these areas. As part of the trial-and-error process inherent in bogusing, it was discovered that over regions where the first guess was particularly bad, a high density of bogus observations was necessary to correct the first guess to yield values similar to the those in the SA. Figure 4.14 indicates the location of bogus observations used in the analysis. Note the very high density of observations along 30N, where the RAWINS/NCAR-analyzed temperatures at the surface and 1000 mb

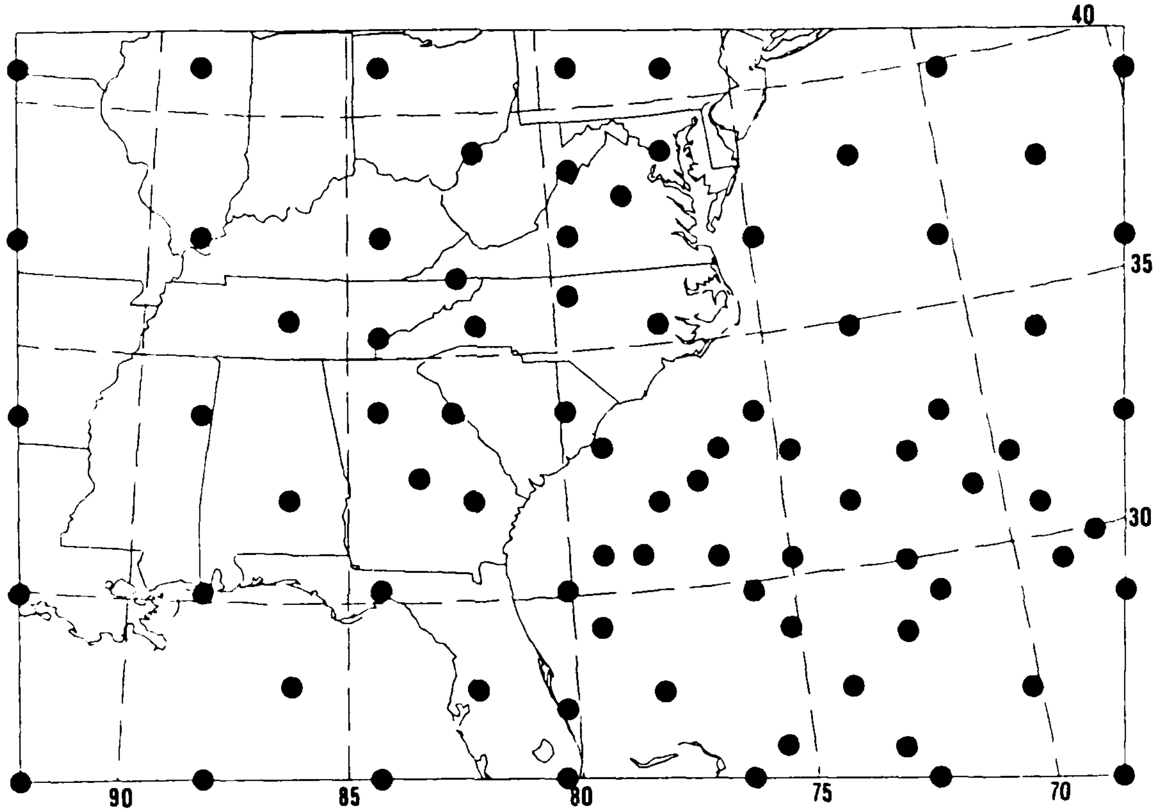


Figure 4.14 Location of bogus observations used to produce the RAWINS/PSU analyses.

were more than 10C too cold. Note also the large number of observations centered over the Appalachian damming region. Without these, the higher temperatures along the coast and west of the Appalachians tended to wash out some of the magnitude of the damming. Around the center of the low, also, many bogus observations were needed to credibly resolve the sea-level pressure.

Bogusing wind values aloft was also difficult because surface wind information could not easily be used to infer wind direction and speed above the surface layer. Wind bogusing was still needed, though, since first-guess wind analyses did not appear compatible with the bogused temperature analyses. Figure 4.15 shows wind vectors from the original RAWINS/NCAR OA overlaid on geopotential heights for 850 mb calculated from the new RAWINS/PSU temperature analyses. At 850 mb, wind direction in the OA is more than 90 degrees ageostrophic near the North Carolina coast and 45 degrees ageostrophic over a large extent of the domain. While Uccellini (1984) points out that a strongly ageostrophic low-level jet existed at this time, this strong ageostrophy should be limited to a fairly small area near the Carolinas.

By geostrophic adjustment arguments, wind bogusing may be necessary to ensure that the bogused temperature structure is preserved. Washington (1964) theorizes that at shorter length scales such as exhibited by the cold-air damming and coastal temperature gradient, temperatures tend

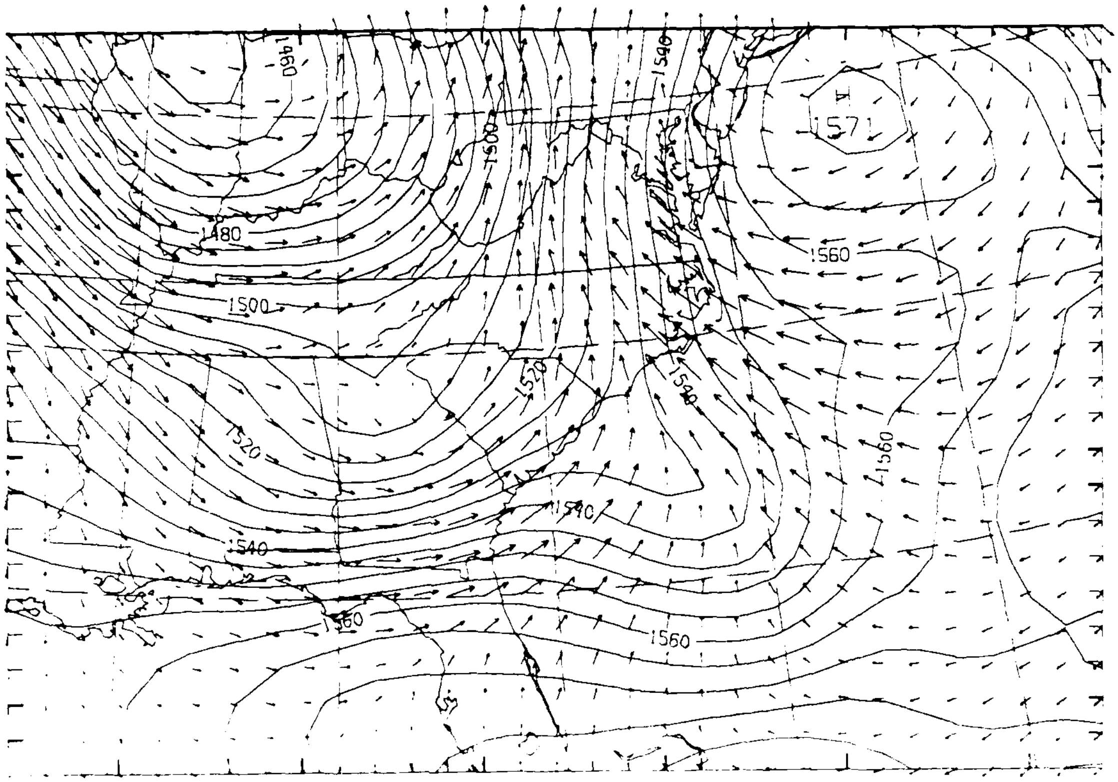


Figure 4.15 RAWINS/NCAR-produced wind analysis at 850 mb overlaid on RAWINS/PSU-produced geopotential heights at 850 mb. A vector 1 grid interval in length ($\mapsto$) is 20 ms^{-1}. The contour interval for geopotential heights is 5m.

to adjust to the wind field rather than vice-versa. Although the modeling study of the 1977 Johnstown flood (Zhang 1985) does not confirm this, his result may be due to the low-level thermal forcing that can alter the unforced adjustment process. When performing the bogusing in this study, it was assumed that the newly bogused temperature structure was crucial to a successful forecast. Thus, because of the poor wind OAs in this case and the possibility of degrading the temperature analyses through geostrophic adjustment with poor quality wind analyses, wind bogusing was performed.

Bogus winds were created over the Atlantic at the surface, 850 mb, and 700 mb. Surface wind bogusing was guided by a subjective streamline and isotach analyses. Bogus surface winds were also added in over the damming region to increase the magnitude of the northerly ageostrophic flow (Figures 4.8 and 4.12). At 850 mb, a streamline analysis (Figure 4.4) was created using geostrophic winds and the OA as a guide. Bogus wind speeds were determined from an average of the two. At 700 mb, winds were adjusted toward geostrophic values in an objective process. In this case, bogus wind directions and speeds were determined by taking the average direction and speed between the first guess and geostrophic values. Bogus values for levels between 700 and 850 mb and between 850 mb and the surface were then determined by linear interpolation, as they are done in RAWINS/NCAR.

4.3.2 Limitations of the Experimental Method

Three notable limitations exist with the new experimental method, as currently used in MM4. First, the software cannot totally eliminate the time involved in typing and compiling the data, though it eliminates many of the possibilities of making errors. Second, the graphics software, SIGMA, lacks some flexibility in displaying output, especially with wind data. Third, although potentially saving time, the new software adds complexity to what is already a complex modeling process.

Consider the first of these limitations. As designed now, the bogusing software helps the user format his data automatically and calculates such important parameters as the latitude and longitude. Nonetheless, the user must still type in the data by hand. If the user has 50 bogus data points, is entering data at 5 levels, and alters temperature, moisture, and winds, this then requires 2000 data entries, not counting further additions during subsequent iterations of the procedure. Furthermore, the postprocessing software adds overhead. For the storm case addressed in Chapter 4, the postprocessing software to generate the bogus master file took approximately five minutes to run. Thus, there is a noticable time delay between data entry and the time RAWINS/PSU can be run. Since bogusing involves trial and error, these five minute intervals can add up to a significant amount of time.

Future modifications to this software may minimize these time-consuming activities. Many improvements to the bogusing software can be envisioned. An additional postprocessing program could be developed which takes data from the previous iteration of the postprocessor and simply makes minor modifications to this output file as needed. Data entry could be simplified by having the software emulate a spreadsheet; also, the "mouse" could be utilized to save keystrokes. Further in the future, software could be developed to allow instant modification of data while plotting a Skew-T. The user could use the mouse to redraw temperature and dewpoint curves, for example, and the software would automatically save and format these changes.

The second limitation is imposed by the graphics software, SIGMA. The program was originally designed to work with NCAR's cloud model but was later redesigned to work with MM4 output. The software was not designed for integration with OA software, however; several compromises have been accepted temporarily but should be addressed with future software development. Most notably, many of the graphics subroutines can not use OA output as their input. Specifically, SIGMA was designed to use the original, three-dimensional disk-mapped arrays as input to some of its more important routines, such as the cross-section and streamline routines. Currently, the software will not allow overwriting of the first guess disk-mapped arrays with OA output, so output must be stored in newly created

2-dimensional arrays. As a result, software will have to be written to build three-dimensional arrays from these two-dimensional arrays. This presents more problems, because the RENAME and COPY functions must be used in this process, and they currently do not work properly with disk-mapped files.

The last limitation concerns the MM4 modeling process. The development of this software addresses the most troublesome step, yet it still leaves many problems intact and adds a new level of complexity. The MM4 process requires human intervention throughout because its enormity and complexity make errors inevitable. As shown by the flowcharts in Figures 3.2 and 3.3, interactive bogusing increases the complexity. Thus, there is a tradeoff in using the software: to benefit from this new method, one must first make the investment in time to master the new software. Further, the user may find the software somewhat over-generalized and may need to add features particular to his case study. If so, this requires more time investment to understand the code and design and test modifications. It is anticipated that future users will make improvements to the system as necessary for their own research. It may then be many years before this software becomes relatively complete and satisfactory to all future users.

It is difficult to estimate the time savings made possible by using ths software. This case study analysis was performed concurrently with software design and debugging, so the actual time taken to create the new initial conditions is not representative for future users. For a case with similar complexity as the one described in this research, it is hoped that bogusing will take no more than a few weeks at most to complete.

Chapter 5

CONCLUSIONS

An interactive bogusing software package has been developed for the PSU/NCAR mesoscale model to decrease the time involved in enhancing OAs for initialization. This software consists of three parts: the bogusing software, which allows the efficient creation of bogus data, the OA software, to analyze the contribution of the bogus data, and the graphics package, to display the output. A test case was performed using the new software. This case demonstrated the capabilities of the software and showed its ease of use. However, further improvements are needed to make the software even more efficient.

Can and should a software package like this be used operationally, say at NMC? One can find many good reasons to believe that such a package would not be very useful operationally. First, consider the difference between the research community and the operational modeling community. Not only does the research community have more time to devote to a specific case, but we have the opportunity to correct specific errors. Here, bogusing is often used to change initial conditions to improve model output. Since research into mesoscale proecesses is relatively new, the environmental conditions necessary to produce the phenomena may not be known. Thus, bogusing can be used to change model initial conditions until the phenomena are successfully reproduced. In a sense, then, it is as important to learn what the environmental conditions are that lead to the successful modeling of the process as it is to obtain accurate model output.

The operational community must operate differently. Only one model run can be performed and disseminated to the public because of time constraints. Because of this, there is little or no time to experiment with improving the initial conditions or to use creativity or meteorological insight. If a bogusing software package like the one described here were to be used operationally, its use would probably be limited to bogusing observations thrown out of or not included in the original analysis. This could be a very useful capability, however. For example, the case mentioned by Reed and Albright (1986) would not have been so poorly forecast had not a couple of ship observations not been thrown out by the objective error-checking software.

Ultimately, however, both the research and operational communities must concentrate on improving OA and initialization algorithms. Research into four-dimensional data assimilation (4DDA) techniques partially addresses this problem. As the rawinsonde network is gradually replaced or supplemented by advanced measurement systems, new analysis technologies will be needed to make better use of the new, continuous-sensing instruments such as Doppler profilers. Nonetheless, interactive analysis software should not be neglected in the future. The less formally constrained human thought pattern can have distinctive advantages over OA algorithms. A discussion of some of the more unusual possibilities for human-machine interaction will be discussed in Section 5.2 after the improvements needed for the software described in this research are briefly addressed.

5.1 Improvements to the PSU/NCAR Mesoscale Model Software

The bogusing software described in this thesis was created to improve the MM4 modelling process. MM4 is very sophisticated, yet it has problems which should be addressed. It would be a great step forward to have MM4 evolve into a "Community Mesosocale Model," an analog to NCAR's Community Climate Model. The major problem with MM4 is its unfriendliness. The author spent three months getting the preprocessing programs and RAWINS/NCAR working for the first time. To use this model, the user must become unnecessarily familiar with the programs and operating system and their idiosyncracies. Ideally, these programs should be usable by persons other than professional meteorologists or computer scientists. This would require that a simpler process be set up requiring less human intervention. Such a development process is being considered and should be given priority.

Though the user-interface to these programs should be simplified, their sophistication should not. RAWINS/NCAR was recently improved so that all analysis options were specified in an easy-to-change "master input file." Unfortunately, at the same time that the user-interface was simplified, its capabilities were diminished. Previously, RAWINS/NCAR could use surface observations and ship and buoy data in the analysis. This is no longer possible. In the case study addressed in this thesis, the author believes that the OA initial conditions would have been significantly improved had this nonstandard data been included. As noted, bogusing was primarily needed to remedy the poor low-level wind and temperature analyses off the Atlantic coast. Had this nonstandard data been included in the surface analysis, this problem would have been greatly diminished. RAWINS/NCAR is designed to generate first guess fields for nonstandard levels (in this case, 950, 900, 800, and 750 mb) only after a surface analysis has been performed. As a result, 1000, 950, and 900 mb first guess fields, which would be obtained in an interpolation between the surface and 850 mb, would also have been much more accurate with a superior surface analysis. In the near future, then, RAWINS/NCAR should be improved once again so that it includes surface data. Should MM4 evolve into the Community Mesoscale Model, it will be very important to have as sophisticated an OA as possible; also, it may not be appropriate to assume that all users will have the meteorological skills necessary to use the bogusing software.

The bogusing software still needs much improvement, too. As mentioned before, it is currently very burdensome to display RAWINS/PSU generated wind analyses using SIGMA software, and the data creation software could be made faster and more user-friendly. It is expected that most of these improvements will be undertaken in the coming months.

5.2 Future Possibilities for Man-Computer Interaction in the Objective Analysis Process

Though the interactive bogusing software developed here may have only limited usefulness in an operational setting, the concept of human-machine interaction is still an important one. Consider for example, an OA program allowing the user a choice of analysis methods and data sources. This program could be very useful. Before starting the OA, the analyst may sit down at his computer and examine satellite imagery over the Pacific. Noticing a cloud leaf indicative of a developing storm, the analyst decides to include satellite temperature and wind data into the analysis in a twenty degree box around the storm. Further, the analyst decides to perform a variational analysis in that area, since satellite data resolves gradients very well and variational analysis routines are mathematically most suitable to assimilating these data. Next, suppose the analyst notes a hurricane off the Mexican coast for which there is no other data available. Using the software, he enters a menu of composite hurricane structures. After comparing the satellite data with the different storm structures, he chooses the one which is most similar, and bogus data for this storm is then automatically assimilated into the OA. Such capabilities are not unreasonable and could significantly improve the ability to predict the evolution of storms in data-poor regions.

For smaller scales, man-computer interaction could again be useful. Currently, the emphasis in NWP research is on improving the capability to forecast precipitation and severe weather more accurately. Both of these require improvements in resolving and modeling mesoscale processes properly. Zhang and Fritsch (1986) noted improvements in their precipitation forecasts of the 1977 Johnstown flood after the inclusion of bogus data into the model. Operationally, we may find that improvements in the prediction of mesoscale processes will require more detailed analyses. While bogusing of the sophistication done by Zhang and Fritsch is not possible operationally, interaction with the OA is. Software could be developed which would allow the analyst to inform the OA software of specific areas where special analysis rules should be used or special data included. For example, this software might allow the analyst to redraw temperature contours with a light pencil in the vicinity of a front, and the OA algorithms could be designed to minimize the smoothing of contours in this area.

Ideally, the final analysis used as input to the model would reflect the best aspects of both the human and the machine. The human has the ability to define areas where the gradient should be tightened or relaxed or where the OA is poor due to lack of data. The machine can perform calculations many orders of magnitude faster, and its preprogrammed algorithms can ensure that the data are dynamically balanced and suitable for input into the model. Though human interaction can potentially make the final analysis more accurate, this will almost always result in a loss of efficiency. An appropriate solution would thus be to program the computer to emulate the human thought process. Artificial intelligence may thus be of great relevance to the future of OA. It is possible that increased data density may obviate the need for incorporating the advantages of human subjectivity. However, this high data density may prove to be prohibitively expensive. In such a case, we should consider improving the sophistication of OA algorithms to have them emulate the human analyis process.

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